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CAST ALUMINUM STRUCTURES TECHNOLOGY (CAST)

THE BOEING COMPANY
SEATTLE, WASHINGTON 98124

MAY 1977

TECHNICAL REPORT AFFDL–TR–77–36
FINAL REPORT, PHASE I–JUNE 1976–FEBRUARY 1977

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of CAST is to establish the necessary structural and manufacturing technologies and to demonstrate and validate the integrity, producibility, and viability of cast aluminum primary airframe structures.

The baseline design is the AMST prototype YC-14 and the component selected was the Nose Landing Gear Support Bulkhead. (Over)

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Preliminary design activities are described that were aimed at a minimum goal of 30% acquisition cost savings with no weight penalty.

Preliminary design data were developed, and a design recommended that could save 38% on cost and result in a 10-pound weight savings.

FOREWORD

This report was prepared by the Boeing Military Aircraft Division of The Boeing Aerospace Company, Seattle, Washington under USAF Contract No. F33615-76-C-3111. The contract work was performed under project 486U under the direction of the Air Force Flight Dynamics Laboratory, Advanced Metallic Structures/Advanced Development Program Office, Wright-Patterson AFB, Ohio. The Air Force Deputy Program Manager was John R. Williamson of the AMS Program Office, Structural Mechanics Division, Air Force Flight Dynamics Laboratories.

The Boeing Aerospace Company, Military Airplane Division, is the contractor, with Mr. Donald E. Strand as Program Manager. This phase of the program was conducted by Mr. Richard C. Jones with C. J. Romero, C. K. Gunther, C. E. Parsons, and D. D. Goehler; and Mr. Walter Hyler of Battelle Columbus Laboratories, subcontractors.

The contractor's report number is D180-20526-1. This report covers work from June 1976 through February 1977.

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SECTION I

INTRODUCTION

The purpose of the CAST program is to demonstrate that aluminum castings can be used for primary aircraft structural components. The program goal is to achieve the above with no weight penalty and with a minimum of 30% cost savings. The baseline airplane selected for the CAST program is the YC-14 prototype AMST. This airplane provides multiple choices for baseline components and is at a development stage such that near-term implementation is a definite possibility.

The Phase I objective is to establish the design configuration to be continued in Phase III, "Detailed Design," and to provide preliminary data and criteria for all following phases of the program.

The preliminary design phase (Phase I) consists of: baseline component selection from YC-14 candidate components and compilation of baseline component data for comparison purposes; establishment of design criteria to be used throughout the program including design strength, fatigue, durability, and damage tolerance criteria; development of preliminary design allowables data for A357 aluminum casting alloy to be used for design until completion of allowables testing; design of a minimum of three conceptual configurations with supporting cost and weight data compiled for selection of the design configuration to be used in Phase III (Detailed Design); and an on-site design review covering Phase I activity plus a recommended selection and customer approval of the design configuration.

This report summarizes the work completed during Phase I.

SECTION II

PRELIMINARY DESIGN

The Phase I Preliminary Design efforts were directed toward determining conceptual casting configurations for testing and possible detail design application and to compile preliminary design criteria, allowables data, damage tolerance methodology, and test plans.

BASELINE COMPONENT

At the beginning of Phase I, the YC-14 structural assembly candidates for baseline component were reviewed and selections made, based on the following requirements:

- Primary airframe structure
- Large complex structure with both heavy and thin sections to provide casting challenge
- Good potential for cost reduction
- Potential for no weight penalty
- Cost effective structural test capability
- Potential for near-term application
- Accessibility for inspection in airframe

The component assemblies selected for final comparison were:

- Station 170 Body Bulkhead (Figure 1)
- Wing Box Nacelle Rib (Figure 2)
- Fin Tip Rib, including Stabilizer Support Assembly (Figure 3)
- Aft Body Bulkhead-Lower Segment (Figure 4)

A trade study chart was prepared (Figure 5) to provide a comprehensive comparison of the candidate component assemblies with the characteristics and criteria for the casting application.

A review of the trade study chart clearly shows that the Station 170 Body Bulkhead is the best choice for the baseline component. This component has the best potential for meeting the cost and weight objectives, possible near-term implementation, and ease of inspection access. The Wing Box Nacelle Rib is first alternate, with a good rating except for structural test complexity and poor accessibility for inspection. The Aft Body Bulkhead-Lower Segment and the Fin Tip Rib were judged consecutively lower in meeting the baseline component criteria.

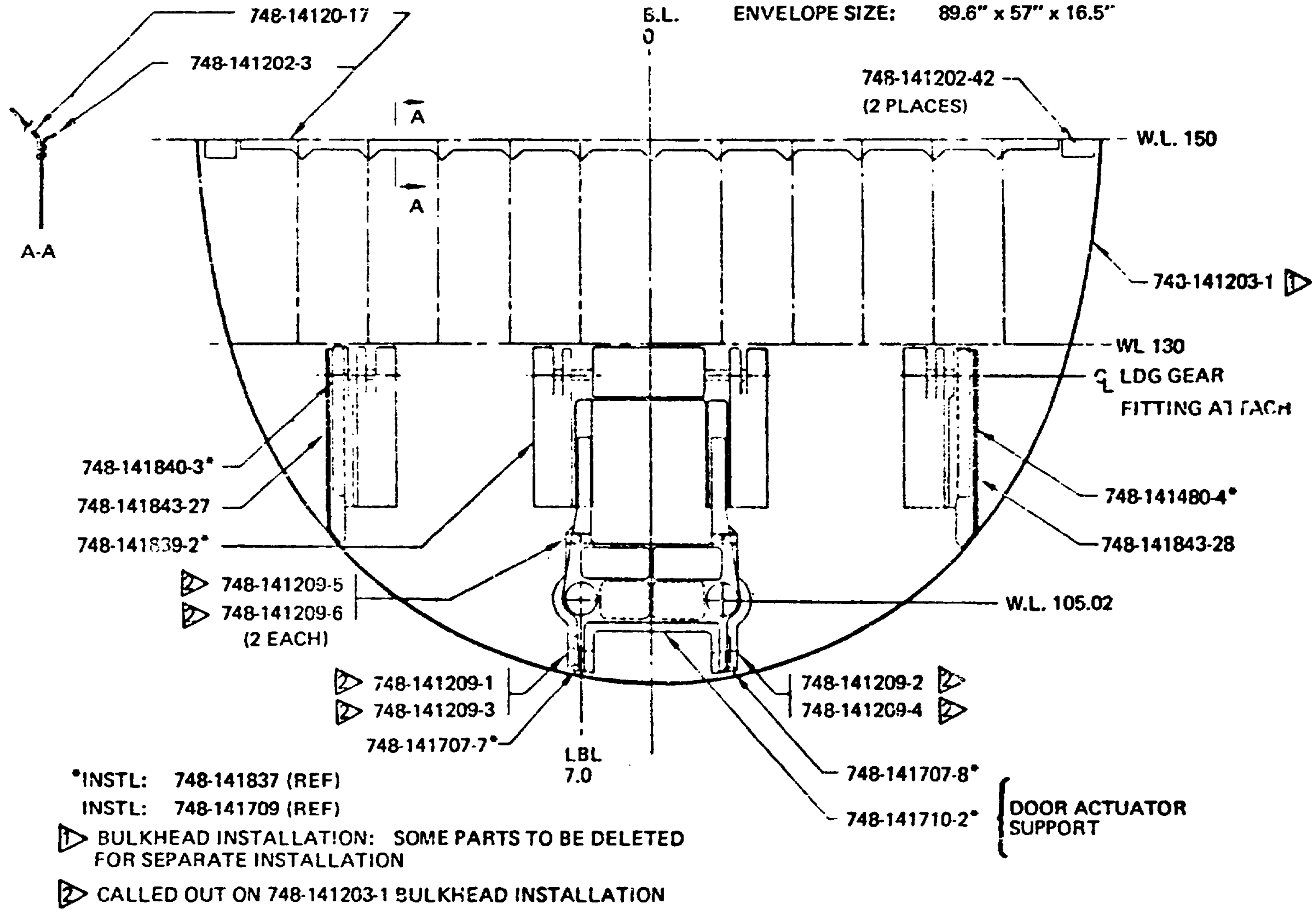

Figure 1. STA 170 Body Bulkhead

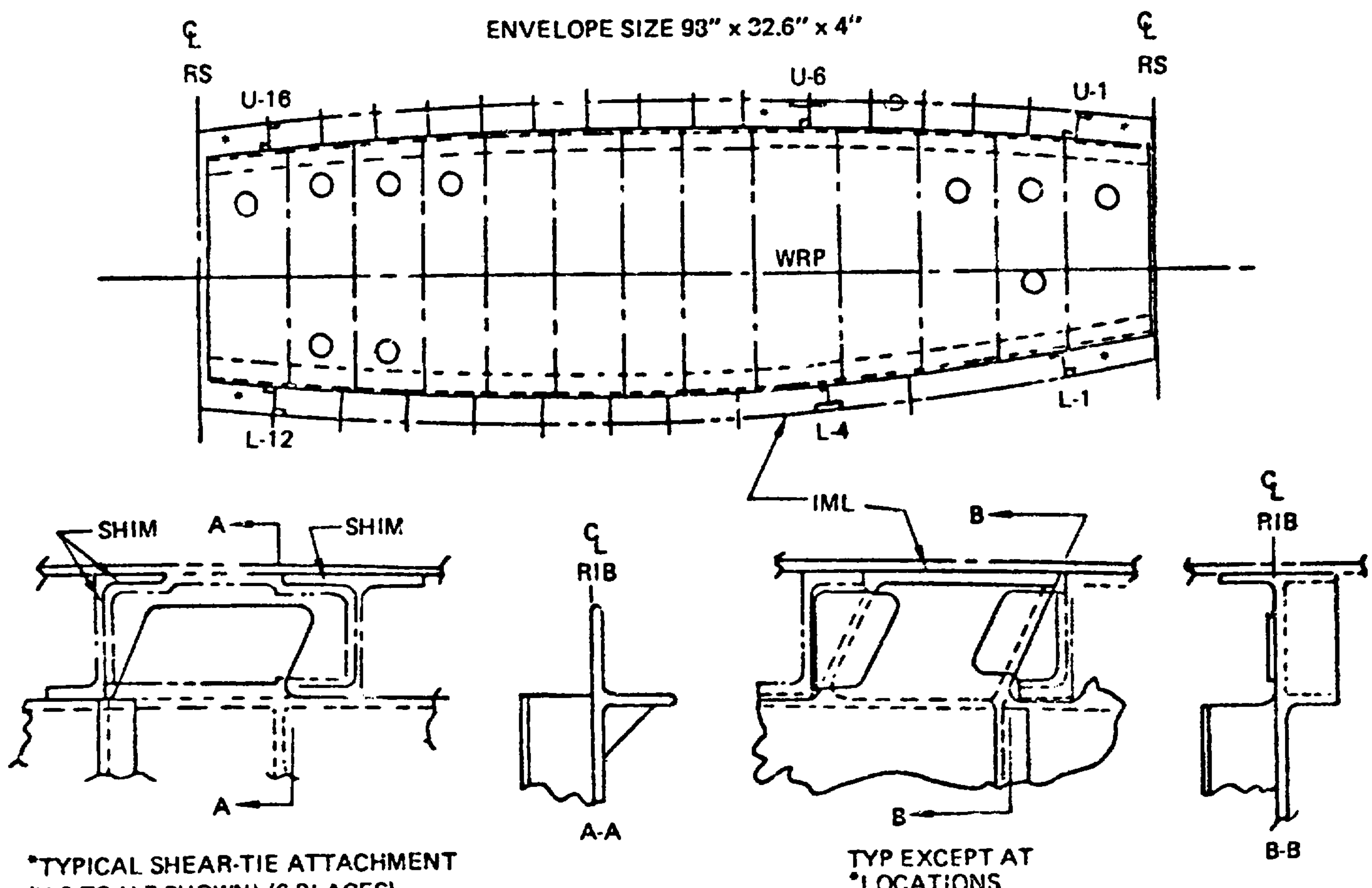

Figure 2. Rib Installation, BL 213, Inspar, Wing

ENVELOPE SIZE: 144" x 44" x 17.5" & 26.5" x 38" x 29'
(2 SEPARATE CASE COMPONENTS WOULD BE REQUIRED)

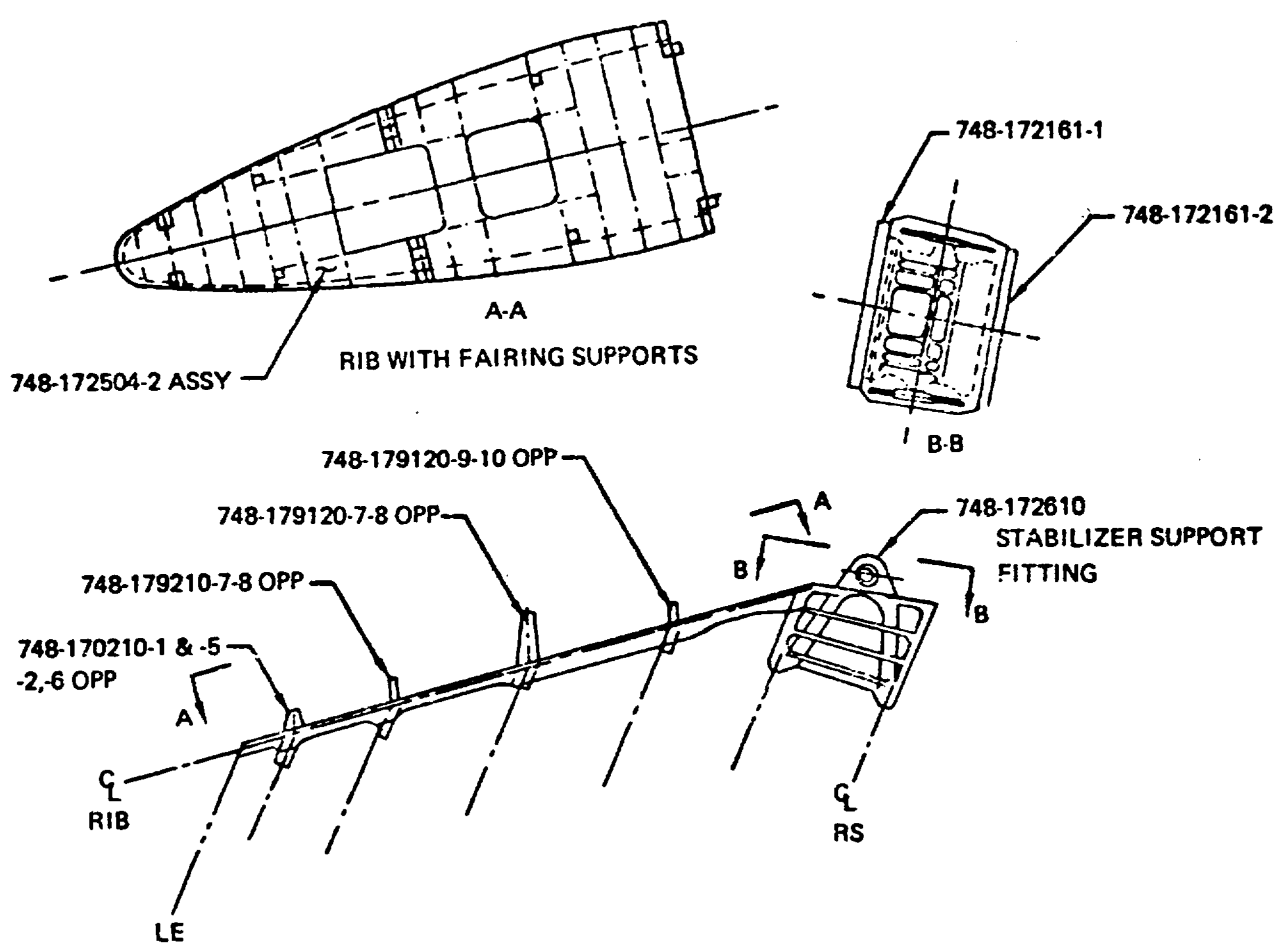

Figure 3. Rib Assembly — Upper Closure, Vertical Fin

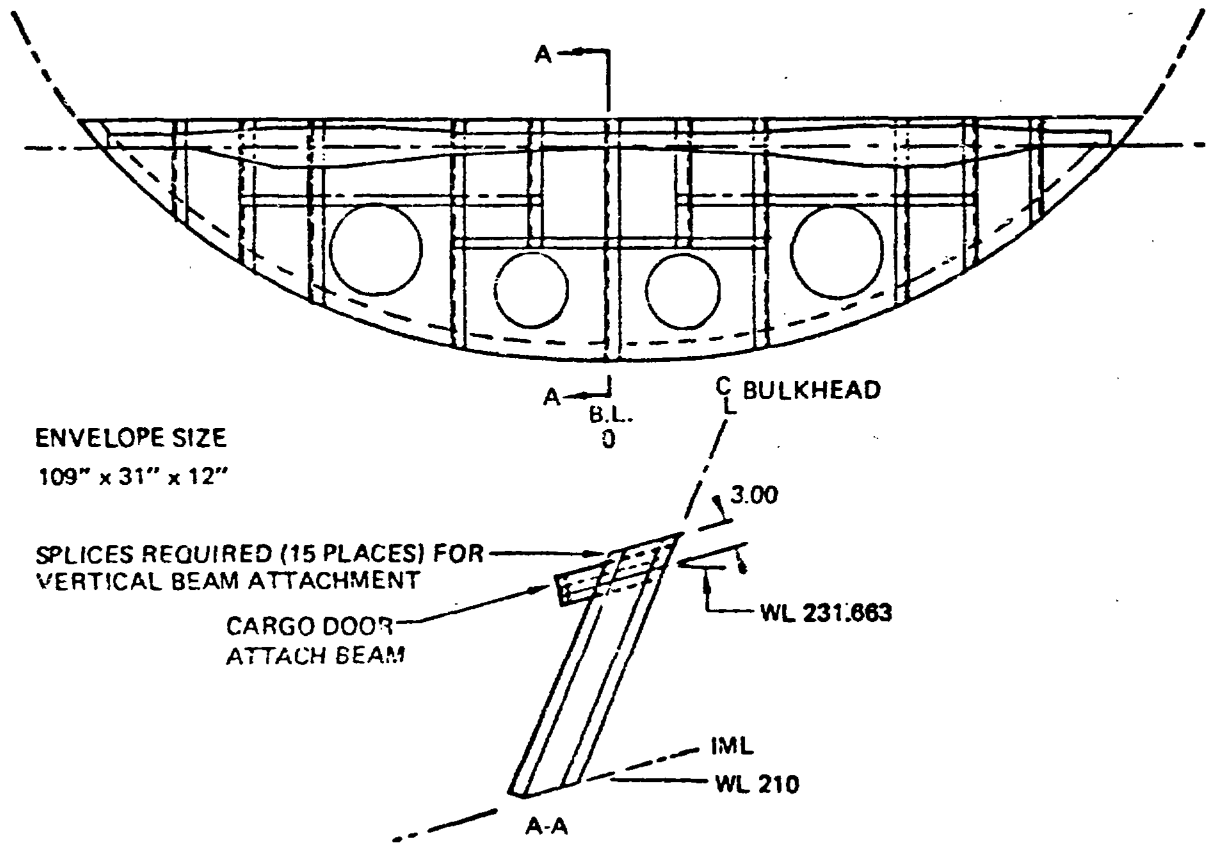

Figure 4. Aft Body Bulkhead — Lower Segment

	STRUCTURAL APPLICATION	SIZE (IN.)	CASTING TECHNOLOGY CHALLENGE	EXISTING C (INCLUDING COMMENTS COST R
1. FIN TIP RIB WITH STABILIZER SUPPORT ASSEMBLY	END RIB OF FIN TORQUE BOX, PRIMARY SUPPORT FOR HORIZONTAL STABILIZER & FIN TIP FAIRING, NOT PRACTICAL TO MAKE AS ONE-PIECE CASTING. FWD RIB WOULD BE ONE PIECE & AFT WOULD BE 3–PIECE CASTING FOR FAIL–SAFE STABILIZER ATTACH STRUCTURE.	FWD: 144 x 44 x 17.5 AFT: 26.5 x 38 x 29	VERY COMPLEX REQUIREMENTS FOR CASTING ALMOST TO THE POINT OF BEING IMPRACTICAL. REQUIRES SEVERAL SEPARATE CASTINGS.	$28,475 POOR POTE COST REDU MULTIPLE, C PARTS ARE EXTENSIVE MATING PA REQUIRED
2. AFT BODY BULKHEAD–LOWER SEGMENT	CARRIES CABIN PRESSURE LOADS AND SUPPORTS LOWER SEGMENT OF TAIL FAIRING. THE CROSS BEAM IS THE PRIMARY LOWER BULKHEAD CHORD AND SUPPORTS AFT END OF THE CARGO DOOR.	100 x 31 x 12	STRAIGHTFORWARD CASTING POTENTIAL. LARGE SIZE WITH MAINLY THIN SECTIONS.	$26,870 GOOD POTE COST REDU ASSEMBLY INSTALLAT ADDITION
3. WING BOX NACELLE RIB (B.L. 213)	SUPPORTS AERODYNAMIC SHAPE OF WING BOX, PROVIDES SUPPORT FOR NACELLE AND DISTRIBUTES NACELLE LOAD THRU SHEAR INTO WING BOX. RIB AND SHEAR TIES FORM A FUEL TANK END RIB.	98 x 33 x 4	LEAST CHALLENGE OF THE GROUP. FLAT SECTION IS MOST PRACTICAL TO CAST. LARGE SIZE WITH THICKNESS RUNNING FROM MINIMUM TO APPROX. .50 IN.	DATA NOT A ($28,360 EST $/FT^2 BASIS POTENTIAL REDUCTION CASTING CH REPLACEME MACHINED
4. BODY BULKHEAD – STATION 170	PROVIDES SUPPORT AND REACTS LOADS FOR FORWARD NOSE GEAR ATTACH POINT AND NOSE GEAR DOOR ACTUATOR SYSTEM. UPPER SEGMENT CARRIES CABIN PRESSURE, PROVIDES SUPPORT FOR NOSE RADOME.	89.6 x 56.2 x 9.6	STRAIGHTFORWARD BUT CHALLENGING. LARGE SIZE WITH A WIDE RANGE OF SHAPES AND THICKNESS, RUNNING FROM MINIMUM TO APPROX. 1.5 IN.	$82,835 VERY GOOD COST REDUC PART REPLA MACHINED N ATTACH FIT

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EXISTING COMPONENT COST (INCLUDING TOOLING) & COMMENTS ON POTENTIAL COST REDUCTION	COMPONENT WEIGHT & POTENTIAL WEIGHT CHANGE	STRUCTURAL TEST COMPLEXITY	POSSIBLE NEAR TERM IMPLEMENTATION	INSPECTION …
$28,475 POOR POTENTIAL FOR COST REDUCTION AS MULTIPLE COMPLEX CAST PARTS ARE REQUIRED & EXTENSIVE REVISION TO MATING PARTS ALSO REQUIRED	FWD: 134.3 LBS AFT: 197.5 LBS POOR POTENTIAL FOR EQUAL WEIGHT, ESPECIALLY IN AFT SEGMENT WHERE LARGE PARTS ARE HIGHLY LOADED. (LWR CASTING ALLOW.)	SIMPLE LOAD CONDITIONS – TORQUE BOX END PLUS ELEVATOR HINGE LOADS. NO PRESSURE LOADS COMPLEXITY FACTOR = .85	REQUIRES EXTENSIVE REVISION OF MATING FIN STRUCTURE IN THE STABILIZER SUPPORT AREA. LARGER HINGE FITTINGS DUE TO LWR CASTING ALLOWABLES REQUIRES REVISION TO HORIZONTAL STABILIZER HINGE FITTINGS.	REQUIRES SC… PICKER. DIF… FIN STRUCTU… OF FIN TIP R… ACCESS THRU… HORIZONTAL…
$26,870 GOOD POTENTIAL FOR COST REDUCTION OF ASSEMBLY BUT INSTALLATION REQUIRES ADDITION PARTS	83.5 LBS POOR POTENTIAL FOR EQUAL WEIGHT. ASSUMING THE ASSEMBLY WEIGHT COULD BE EQUALLED, THE SPLICE PARTS FOR INSTL WOULD ADD WEIGHT	NORMAL LOAD CONDITIONS. DOOR HINGE LOADS PLUS LOWER BULKHEAD CHORD LOADS PLUS BODY CABIN PRESSURE COMPLEXITY FACTOR = 1.14	COULD BE REASONABLY IMPLEMENTED. REQUIRES ADDED SPLICE FITTINGS TO 15 EXISTING VERTICAL BEAM-STIFFENERS.	SCAFFOLDING… PORTION ACC… OF LARGE CA… BODY FAIRIN…
DATA NOT AVAILABLE – ($28,360 ESTIMATED ON AVG $/FT² BASIS) VERY GOOD POTENTIAL FOR COST REDUCTION DUE TO LEAST CASTING CHALLENGE & REPLACEMENT OF MULTIPLE MACHINED SHEAR TIES.	80.5 LBS (EA) FAIR POTENTIAL TO EQUAL WEIGHT OF EXISTING STRUCTURE. DECREASE FROM OVERLAP ELIMINATION WOULD MATCH INCREASE FROM LOWER ALLOWABLES.	MULTIPLE LOAD CONDITIONS COMBINED WING BENDING, TORSION AND NACELLE LOADS PLUS FUEL PRESSURE COMPLEXITY FACTOR = 1.28	COULD BE REASONABLY IMPLEMENTED. REQUIRES 6 REDESIGNED SHEAR TIES.	SCAFFOLDING… WING FUEL BE… PURGED FOR A… LOWER SURFA…
$82,835 VERY GOOD POTENTIAL FOR COST REDUCTION. CAST PART REPLACES MULTIPLE MACHINED NOSE GEAR ATTACH FITTINGS.	184.6 LBS GOOD POTENTIAL TO EQUAL WEIGHT OF EXISTING STRUCTURE THE LARGE PART COUNT PROVIDES EXTENSIVE AREA OF OVERLAP REDUCTION TO MATCH INCREASED "T" FROM LOWER ALLOWABLES.	NORMAL LOAD CONDITIONS. NOSE GEAR & NOSE GEAR DOOR POINT LOADS PLUS BODY SHEAR AND BODY CABIN PRESSURE. COMPLEXITY FACTOR = 1.00	COULD BE REASONABLY IMPLEMENTED, REQUIRES CLOSE TOLERANCE LOCATION OF HOLES FOR LANDING GEAR FITTING ATTACH. TO REPLACE SHIM ALLOWANCE ON EXISTING FITTINGS ATTACHED TO BULKHEAD.	EASY ACCESS T… BULKHEAD TH… TO UPPER REA… BAY INSIDE AI… FORWARD SIDE… DOOR. SHORT…

TRADE STUDY CHART

Figure 5

...PONENT WEIGHT ...OTENTIAL WEIGHT ... CHANGE	STRUCTURAL TEST COMPLEXITY	POSSIBLE NEAR TERM IMPLEMENTATION	INSPECTION & MAINTENANCE ACCESS
...3 LBS ...5 LBS ...TENTIAL FOR EQUAL ...ESPECIALLY IN ...ENT WHERE LARGE ...E HIGHLY LOADED. ...TING ALLOW.)	SIMPLE LOAD CONDITIONS – TORQUE BOX END PLUS ELEVATOR HINGE LOADS. NO PRESSURE LOADS COMPLEXITY FACTOR = .85	REQUIRES EXTENSIVE REVISION OF MATING FIN STRUCTURE IN THE STABILIZER SUPPORT AREA. LARGER HINGE FITTINGS DUE TO LWR CASTING ALLOWABLES REQUIRES REVISION TO HORIZONTAL STABILIZER HINGE FITTINGS.	REQUIRES SCAFFOLD OR CHERRY PICKER. DIFFICULT ACCESS THRU FIN STRUCTURE TO LOWER SURFACE OF FIN TIP RIB, UPPER SURFACE ACCESS THRU FAIRING AND HORIZONTAL STABILIZER REMOVAL.
...TENTIAL FOR EQUAL ... ASSUMING THE ...Y WEIGHT COULD BE ...D. THE SPLICE ...R INSTL WOULD ...HT	NORMAL LOAD CONDITIONS. DOOR HINGE LOADS PLUS LOWER BULKHEAD CHORD LOADS PLUS BODY CABIN PRESSURE COMPLEXITY FACTOR = 1.14	COULD BE REASONABLY IMPLEMENTED. REQUIRES ADDED SPLICE FITTINGS TO 15 EXISTING VERTICAL BEAM-STIFFENERS.	SCAFFOLDING REQUIRED. LOWER PORTION ACCESS REQUIRES REMOVAL OF LARGE CARGO DOOR AND AFT BODY FAIRING.
...EA) ...TENTIAL TO EQUAL ...OF EXISTING ...RE. DECREASE ...ERLAP ELIMINATION ...ATCH INCREASE FROM ...LLOWABLES.	MULTIPLE LOAD CONDITIONS COMBINED WING BENDING, TORSION AND NACELLE LOADS PLUS FUEL PRESSURE COMPLEXITY FACTOR = 1.38	COULD BE REASONABLY IMPLEMENTED. REQUIRES 4 REDESIGNED SHEAR TIES.	SCAFFOLDING REQUIRED. REQUIRES WING FUEL BE DRAINED AND TANK PURGED FOR ACCESS THRU WING LOWER SURFACE.
...TENTIAL TO EQUAL ...OF EXISTING STRUC. ...E LARGE PART ...ROVIDES EXTENSIVE ... OVERLAP REDUCTION ...H INCREASED "T" ...WER ALLOWABLES.	NORMAL LOAD CONDITIONS. NOSE GEAR & NOSE GEAR DOOR POINT LOADS PLUS BODY SHEAR AND BODY CABIN PRESSURE. COMPLEXITY FACTOR = 1.00	COULD BE REASONABLY IMPLEMENTED, REQUIRES CLOSE TOLERANCE LOCATION OF HOLES FOR LANDING GEAR FITTING ATTACH, TO REPLACE SHIM ALLOWANCE ON EXISTING FITTINGS ATTACHED TO BULKHEAD.	EASY ACCESS TO LOWER AFT PART OF BULKHEAD THRU NOSE GEAR OPENING TO UPPER REAR THRU UNDER-FLOOR BAY INSIDE AIRPLANE. ACCESS TO FORWARD SIDE THRU RADOME ACCESS DOOR. SHORT LADDER REQUIRED.

TRADE STUDY CHART

Figure 5

Baseline Component Data

Costs of the YC-14 Station 170 Body Bulkhead with component parts were derived from actual records. The actual costs could not be isolated to the detail level, so the cost breakdown was estimated based on the overall bulkhead cost. Figure 6 shows the total cost for the two YC-14 units with the unit cost based on the two-airplane run. Figure 7 shows the results of a cost analysis based on: (1) the first unit YC-14 bulkhead total cost, and (2) the projected unit cost of the bulkhead based on a 300-airplane production run. This last unit cost ($10,900) was used for all cost comparisons of cast concepts to baseline component. The cast concept costs are calculated and projected to a 300-airplane production run for direct cost comparison.

The weight of the baseline component was compiled starting with the weight of the Station 170 Body Bulkhead. The weight of the parts of the bulkhead that would not be included in the casting was deleted. These parts included that portion of the bulkhead above WL 150, a seal retainer, and the skin strip across the front of the landing gear bay. The weight of the fittings and attaching parts for mating structure that were not part of the bulkhead assembly but will be included in the cast concept was added. The total weight of the baseline component is 184.6 pounds.

Costs

The following costs were derived primarily from actual records; but in some cases the actuals could not be isolated to the detail level, so calculated estimates were made. Final assembly of the bulkhead was accomplished upon installation and is not included. This deletion is reasonable as the final assembly would compare to the locating, drilling, reaming, and bushing of the landing gear fitting attach-holes after the cast bulkhead is installed. Man-hours and costs noted below are for both units of the YC-14.

	Man-hours	Dollars
Raw material	–	$1,920
Tooling	3,178	79,450
Fabrication	2,838	70,950
Sub-assembly	534	13,350
Total (2 units)	6,550	165,670
Each unit (2 unit run)	3,275	82,835

Figure 6. Baseline Component Data: YC-14 Bulkhead Assembly, Body Station 170

YC-14 1st prototype	
Raw material	$ 1,000
Labor	
Tooling	
• Detail tools	35,000
• Assembly tools	43,700
• Detail fabrication*	35,500
• Assembly**	6,700
Total cost	
Cost per unit	$122,700

*Detail fabrication - - Making of 280 parts.

**Assembly - - Assemble and install parts.

C-14-300 shipsets		
	Nonrecurring	Recurring
Raw material		$ 300,000
Labor		
• Engineering	$ 53,000	53,000
• Developmental	16,000	20,300
• Tool design and fabrication	530,000	53,900
• Production and production planning	22,000	2,072,400
• Quality control	34,000	120,000
Total cost	$655,000	$2,618,600
Average/shipset	$10,900	

Figure 7. Conventionally Fabricated Station 170 Bulkhead Costs (1976 Dollars)

DESIGN CRITERIA

Preliminary Design Criteria

Preliminary design criteria for the CAST component include:

1. All applicable Military Specifications: MIL-A-008860A, MIL-A-008861A, MIL-A-008866B, MIL-A-83444, MIL-STD-1530A.

2. Design allowables verification test requirements.

3. Applicable YC-14 airplane requirements and objectives.

4. Design loads requirements per YC-14 Airplane Strength Analysis.

5. Repeated loads derivation from design usage as noted in the YC-14 Damage Tolerance Assessment Document.

6. CAST design service life requirements (same as C-14 design service life requirements).

7. General requirements including deviation from MIL-A-008860A -- no casting factor.

8. Reliability requirements, durability, and damage tolerance criteria.

The final design criteria document for CAST will be submitted in Phase III per CAST program schedule.

Damage Tolerance and Durability Control Plan

The damage tolerance and durability control plan identifies and defines the tasks necessary to ensure compliance with damage tolerance and durability requirements of MIL-STD-1530A, MIL-A-83444, and MIL-A-008866B.

The test plan for the fatigue and fracture characterization testing of the casting alloy A357 is included in the damage tolerance and durability control plan.

A section of the plan contains the fracture control specification for the Station 170 bulkhead in the event it is declared fracture critical.

A detail description of the flight-by-flight loads spectrum for the bulkhead is attached to the plan. It includes a description of the derivation of the analysis and test load spectrum r damage tolerance and durability analysis and full-scale testing.

The damage growth prediction and durability methodology are described in the plan. A plan for sensitivity studies that will be performed during Phase III of the program is also contained in the Control Plan. These studies will identify the sensitivity of life predictions to material properties, spectrum make-up, aircraft usage, and initial flaw sizes assumed to exist.

PRELIMINARY DESIGN ALLOWABLES DATA

During Phase I, preliminary design allowables were developed for A357-T6 aluminum alloy castings procured to MIL-A-21180. The allowables were developed from data collected and analyzed by Battelle Columbus Laboratories under subcontract to the CAST Program. The data base included 3900 test results representing 47 separate parts from 14 different foundries.

Sixteen strength/elongation classes were represented, including the four classes defined in MIL-A-21180. Table 1 shows the number of results (n) available for each class listed as the minimum required ultimate tensile strength/tensile yield strength/elongation (TUS/TYS/elong.). Average, standard deviation, minimum, maximum, and A and B statistical values were reported by Battelle as shown in Table 1 for each class. Approximately 55 percent of the data were contained in the 50/40/5 class.

Data for TUS, TYS, and elongation of the 16 strength/elongation classes are shown in Figures 8, 9, and 10, respectively. Each of these figures shows the number of results, mean, and the computed A and B statistic for each class.

The CAST preliminary allowables have been established for the four strength/elongation classes of MIL-A-21180 with the same distinctions regarding designated areas or total casting.

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Table 1. Statistics on 16 Classes of A357 Aluminum Casting Data

		$\bar{X}$			S			MIN			MAX			A			B	
TUS/TYS/e	n	TUS	TYS	e	TUS	TYS	e	TUS	TYS	e	TUS	TYS	e	TUS	TYS	e	TUS	TYS
33/27/3	56	44.7	36.0	3.80	5.39	6.47	2.04	33.0	28.0	0.80	55.8	55.5	16.0	26.4	*	*	34.2	28.4
35/28/2	206	46.0	35.9	6.17	2.36	2.17	1.54	36.3	28.8	2.00	52.2	41.9	14.0	39.9	*	*	42.8	31.6
33/28/3	147	51.2	41.1	8.51	1.94	1.80	1.40	46.2	37.9	3.00	57.5	47.5	16.0	46.1	35.4	*	48.3	38.4
38/28/5	149	46.5	36.1	6.46	4.84	4.14	1.66	34.5	29.3	0.60	59.0	50.6	13.0	*	*	*	40.6	31.1
40/30/3	7	43.3	37.7	4.17	2.45	0.80	1.33	39.5	36.2	3.00	47.0	38.8	6.00	29.2	33.1	*	35.0	34.9
40/32/3	87	44.8	34.9	5.13	1.83	2.16	1.52	39.4	28.2	1.80	48.4	38.1	11.0	39.8	*	*	42.0	30.3
41/31/3	341	50.3	41.5	6.31	4.25	3.90	1.50	38.2	31.2	3.00	58.0	48.3	16.0	38.2+	31.2+	3.00+	42.5	34.4
41/36/3	34	51.9	43.1	6.61	1.98	1.62	1.38	49.1	39.4	4.00	55.7	45.8	11.0	45.8	38.2	*	48.4	40.3
41/38/3	113	52.9	44.2	5.75	1.88	1.15	1.42	47.8	41.6	3.00	57.0	46.9	13.0	47.8	41.2	*	50.0	42.5
42/31/3	3	46.3	36.1	5.37	0.67	1.27	1.30	45.7	34.6	4.00	47.0	36.9	6.50	-	-	-	-	-
45/34/3	164	50.3	40.9	7.59	2.68	2.35	1.58	40.3	31.6	1.00	58.2	47.0	15.0	*	*	*	45.5	37.6
45/35/3	29	47.6	36.9	7.41	1.96	1.79	1.39	42.9	33.7	4.00	51.5	41.7	15.0	41.4	31.3	2.59	44.0	33.6
48/36/5	280	51.8	40.5	8.91	1.87	1.62	1.48	48.0	36.2	0.90	56.2	44.7	18.8	47.1	36.4	*	49.2	38.2
48/40/4	126	51.9	42.9	6.76	0.94	1.06	1.21	50.0	40.5	4.00	54.8	45.3	10.5	*	40.0	*	50.7	41.3
50/40/3	12	51.9	43.7	7.94	1.23	2.23	1.30	50.4	40.6	5.00	53.6	48.2	12.0	47.0	34.9	2.77	49.0	38.5
50/40/5	2146	53.0	43.4	7.94	1.68	1.58	1.43	43.7	37.8	1.10	58.8	49.9	18.5	47.1+	39.6+	2.50+	50.8	41.4

* Nonnormal distribtuion, insufficient data to establish A value by nonparametric approach.

\+ Nonnormal distribution, sufficient data, however, to establish A value by nonparametric approach.

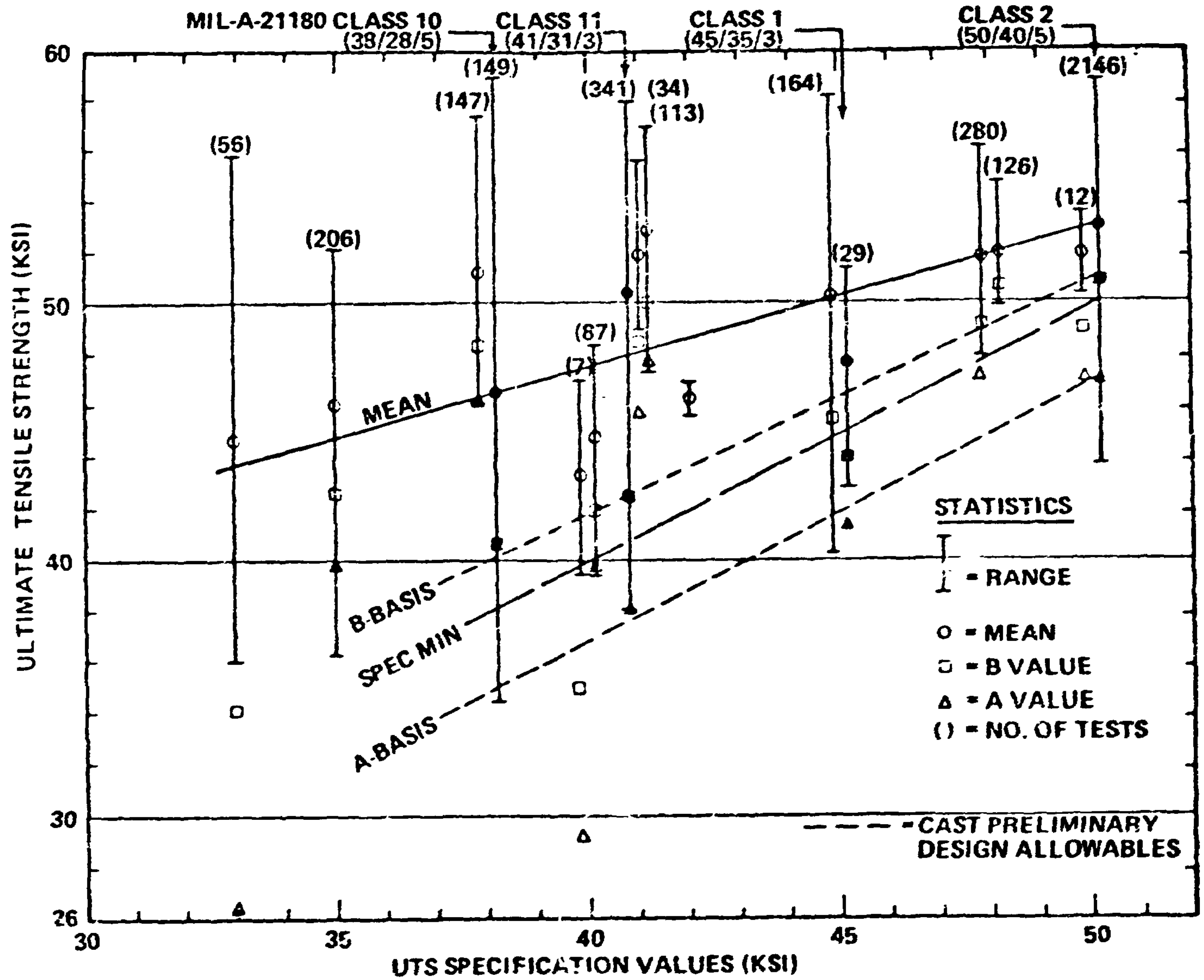


Figure 8. Ultimate Tensile Strength Versus UTS Specification Values

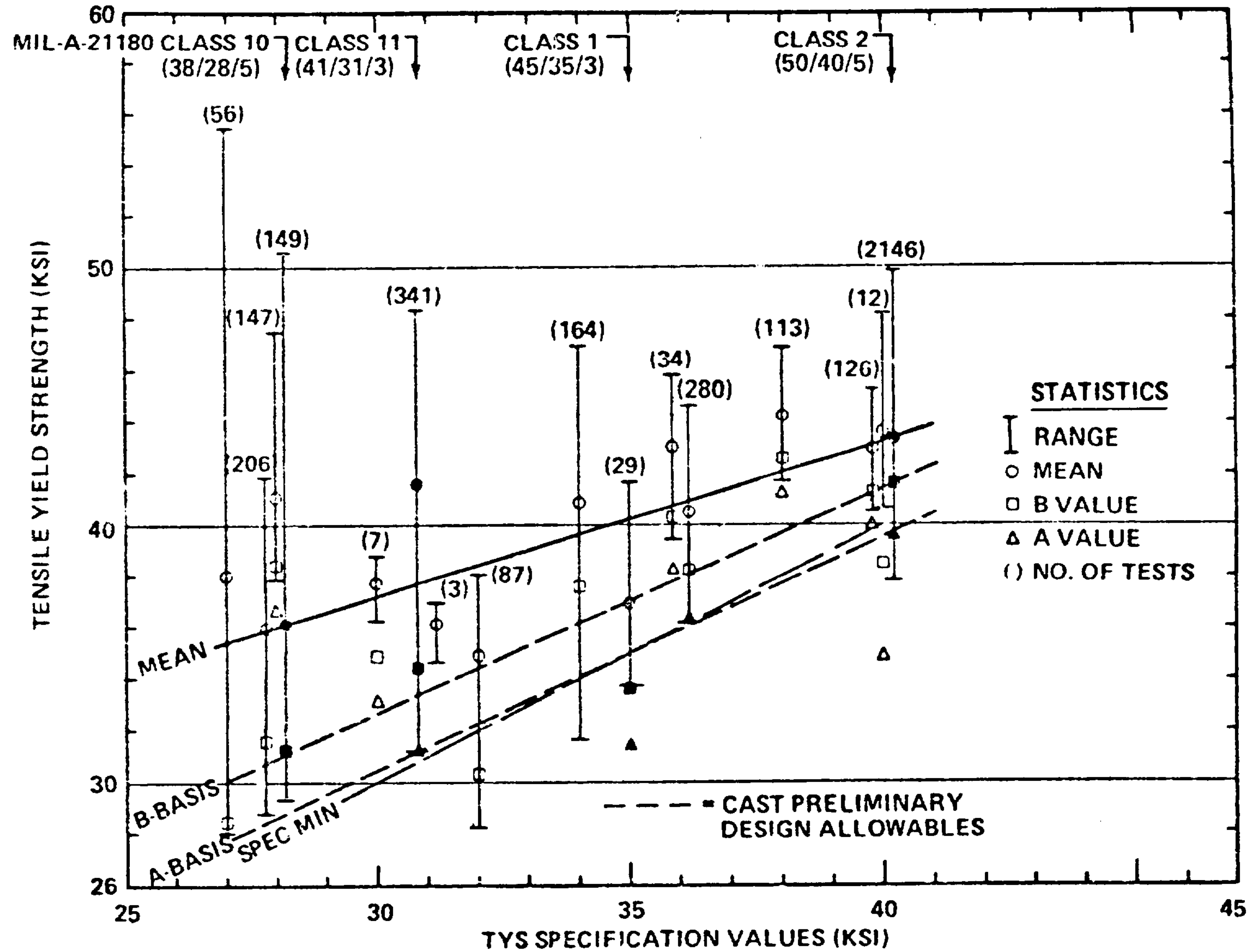


Figure 9. Tensile Yield Strength Versus TYS Specification Values

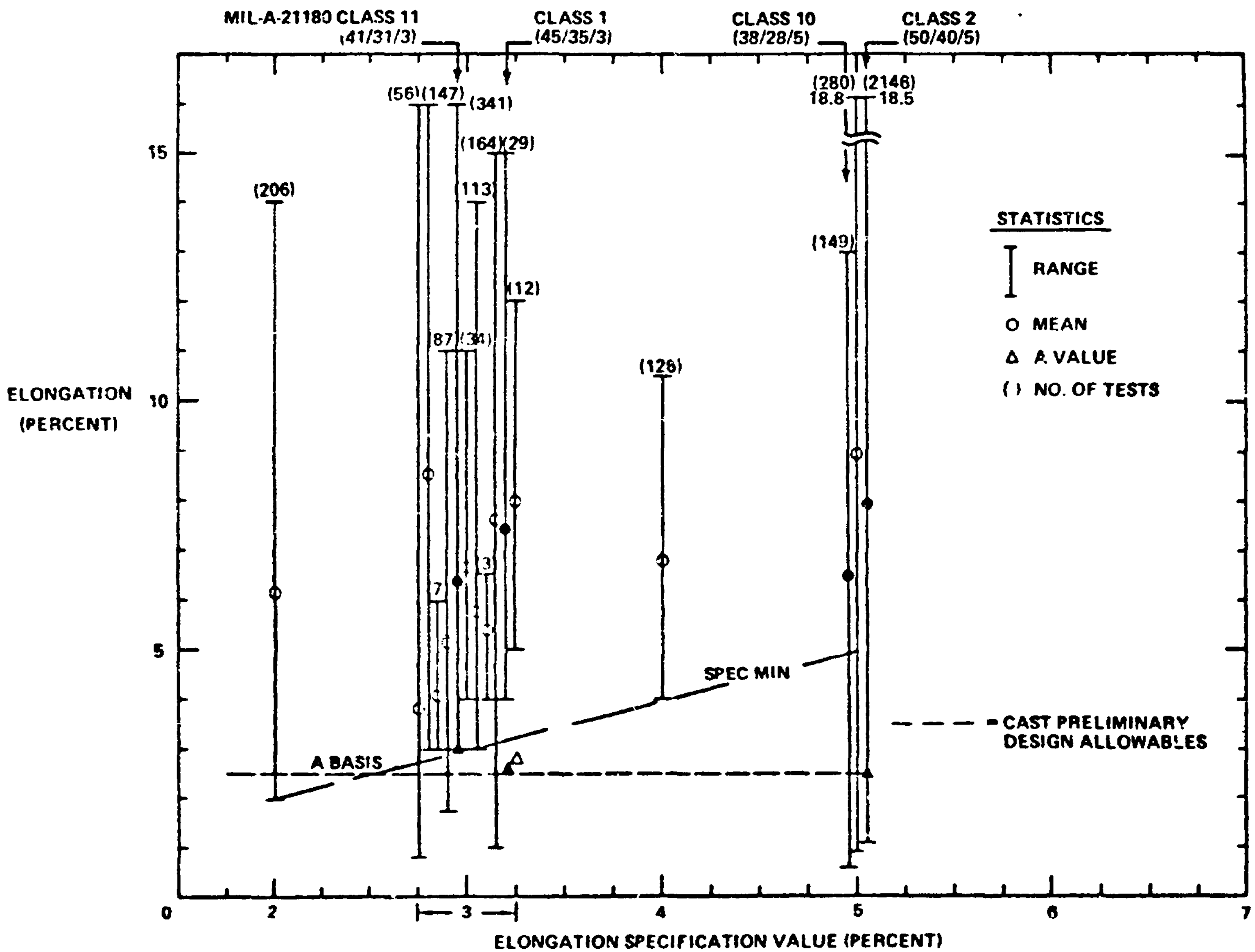


Figure 10. Elongation Versus Elongation Specification Values

These classes are designated as:

- o Class 1 -- 45/35/3
- o Class 2 -- 50/40/5
- o Class 10 -- 38/28/5
- o Class 11 -- 41/31/3

Ultimate tensile strength preliminary design allowables were developed from the data of Figure 8. A straight line through the measured UTS mean values describes the four designated classes, and provides a reasonable fit to the other classes. In turn, straight lines were constructed through the computed A and B values for the four designated classes for which allowables are provided. Class 10 (38/28/5) does not have an A value statistic due to a nonnormal distribution and insufficient data to establish the value by the nonparametric ranking method.

Figure 9 shows the measured tensile yield strength data plotted against the TYS specification values. The same straight line plotting method describes the data reasonably well and was used to develop the A and B allowables.

Measured percent elongation data are shown versus elongation specification values in Figure 10. The range of results within each strength/elongation class is large, from approximately 1 to 15 percent. Since the A values computed for Classes 1, 2, and 11 are essentially the same, a common value of 2.5 percent elongation was established for all values. In accordance with MIL-HDBK-5, a B value was not established for elongation.

The values for F_{cy}, f_{su}, F_{bru}, and F_{bry} were developed from the F_{tu} and F_{ty} values using derived property ratios determined from the values shown for A357.0-T61 in Section 3.13.16 of MIL-HDBK-5B as follows:

- o $F_{cy} = F_{ty}$
- o $F_{su} = 0.7\ F_{tu}$
- o $F_{bru} = 1.4\ F_{tu}$ (e/D = 1.5)
- o $F_{bru} = 1.8\ F_{tu}$ (e/D = 2.0)
- o $F_{bry} = 1.6\ F_{ty}$ (e/D = 1.5)
- o $F_{bry} = 1.8\ F_{ty}$ (e/D = 2.0)

The values for E, E_c, G, and μ are the same as those in Section 3.13.6 of MIL-HDBK-5B for A357.0-T61.

The preliminary design allowables developed for the CAST program are shown in Table 2.

Phase II requires the development of a process (procurement) specification for castings and a test program to obtain final structural design allowables. These allowables will be suitable for design use without a casting factor.

In general, statistical allowables are based on an analysis of a collection of data from material produced to meet the requirements of a specification. In the case of wrought metal products, the properties data are segregated by product form, , sheet, plate, extrusion, forging, associated with the method of producing the material. Also, the method of

Table 2. "CAST" Preliminary Design Allowables

ROOM TEMPERATURE MECHANICAL PROPERTIES Program CAST Preliminary Design Allowables								
Alloy	A357							
Specification	CAST-XXXX							
Form	Castings							
Temper	T6							
Class ①	1		2		10		11	
Basis	A	B	A	B	A	B	A	B
Mechanical properties:								
F_{tu} ksi	42	46	47	52	35	40	38	43
F_{ty} ksi	35	37	40	42	29	31	31	34
F_{cy} ksi	35	37	40	42	29	31	31	34
F_{su} ksi	29	32	33	36	24	28	27	30
F_{bru} ksi								
(e/D = 1.5)	59	64	66	71	49	56	53	60
(e/D = 2.0)	76	83	85	92	63	72	69	77
F_{bry} ksi								
(e/D = 1.5)	56	53	64	67	46	50	50	54
(e/D = 2.0)	63	67	72	76	52	56	58	61
Elong Percent	2.5		2.5		2.5		2.5	
E 10^3 ksi	10.4							
E_c 10^3 ksi	10.5							
G 10^3 ksi	3.9							
μ	0.33							

① Class designations represent strength classes from MIL-A-21180

Program CAST	MIL-A-21180
Class 1	Class 1 (45/35/3)
Class 2	Class 2 (50/40/5)
Class 10	Class 10 (38/28/5)
Class 11	Class 11 (41/31/3)

Classes 1 and 2 represent properties of specimens cut from designated areas

Classes 10 and 11 represent properties of specimens cut from any area of a casting

manufacture of wrought products is generally continuous and/or repetitive in nature and produces consistency in the end product. This consistency and the adherence to a process specification produces a properties population whose characteristics can be described by statistical analyses of past historical samples.

The casting process, however, allows the production of complex configurations of almost unlimited dimensional variability by many different methods and techniques. These processing differences cause uncertainty about the validity of past historical data for describing the characteristics of a future population. This uncertainty is due in part to the following items in the specifications for procuring castings:

1. Many of the requirements for inspection for quality can be exempted by the drawing or purchase order.

2. Strength in the part cannot be verified without destroying the part.

A consequence of these characteristics and the unique nature of the one-of-a-kind casting process is a general lack of structural designer confidence in castings.

The proposed elimination of the casting factor will require a means for qualifying foundries and a new procurement specification that will assure the required quality or integrity in each part.

CASTING CONCEPT CONFIGURATIONS

Three different cast concepts of the Station 170 body bulkhead were completed to obtain cost, weight, casting method, and structural comparison. The three concepts with design approach rationale were:

- Stiffened Web Concept (Figure 11) -- This configuration was chosen for study on the basis of being the most direct design approach. The idea was to design a casting that physically matched the existing bulkhead structure as closely as possible; to provide continuity of existing structural load paths and require no revision to existing adjacent structure. The resultant one-piece cast configuration is similar to the baseline component built-up structure.

- Hybrid Concept (Figure 12) -- During the proposal effort and early in the preliminary design phase, the ability to cast large areas of thin web was in doubt. This concept was to provide a cast framework including all the heavy structure and fittings, with a sheet web mechanically fastened to the cast frame for shear and pressure loads. The primary tradeoff was the thin, higher allowable web plus the frame overlap versus the all-cast one-piece structure.

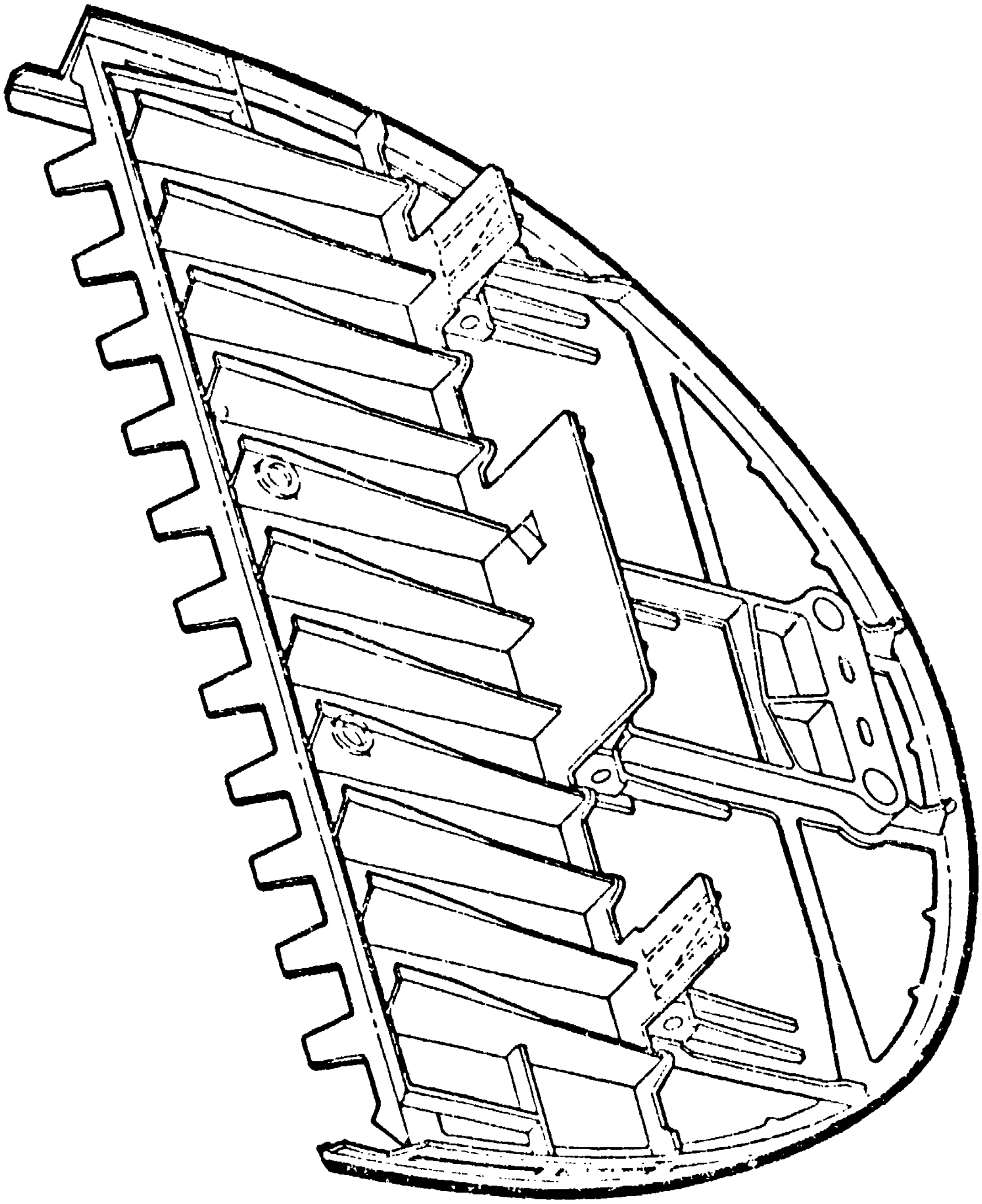


Figure 11.Concept No. 1, Stiffened Web

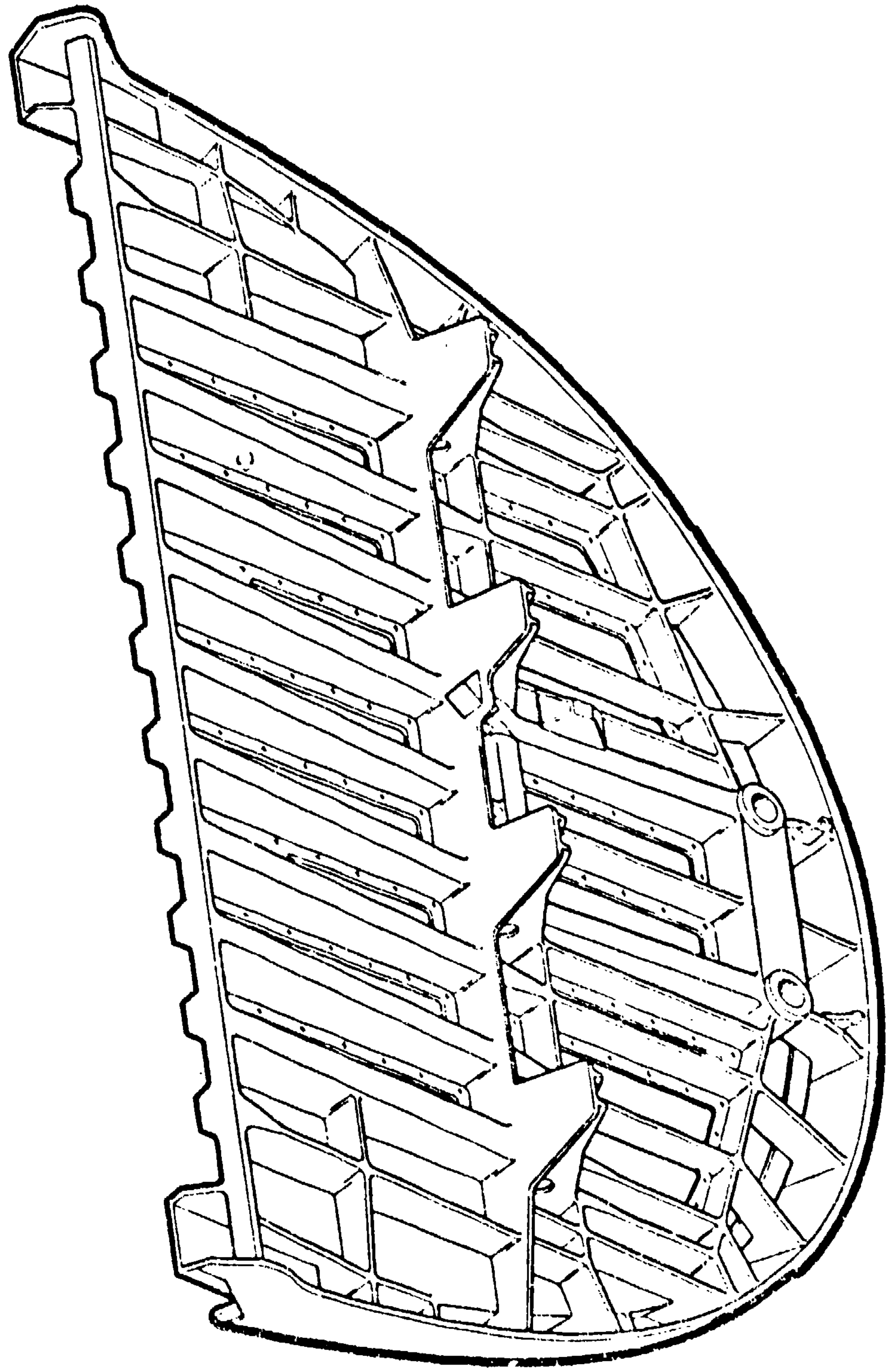


Figure 12. Concept No. 2 Hybrid

- Truss Concept (Figure 13) -- Another design to reduce the requirement for a thin cast web is the truss configuration. This design concept was to take advantage of the thick cross-section members to transfer loads through tension and compression only, deleting the requirement for a web in the nonpressurized area. It was anticipated that the casting simplification of this concept would reduce cost with little weight increase.

Concept Drawings

Layout drawings of the Station 170 bulkhead were made for each of the three cast concept configurations and distributed to Structures Staff and the Casting Foundry for analysis, comments, and required revisions. The layout drawings were subsequently completed and sent to Manufacturing and Weights for cost and weight analysis.

Stiffened Web Concept (Cast Concept #1)

The stiffened web concept was designed to meet the following goals:

- Basic YC-14 dimensional and strength requirements
- Minimum weight
- Least effect on existing mating structure
- Inclusion of all parts of Baseline Component
- Match of cast structure to existing structural load paths
- Maximum cost reduction consistent with above goals

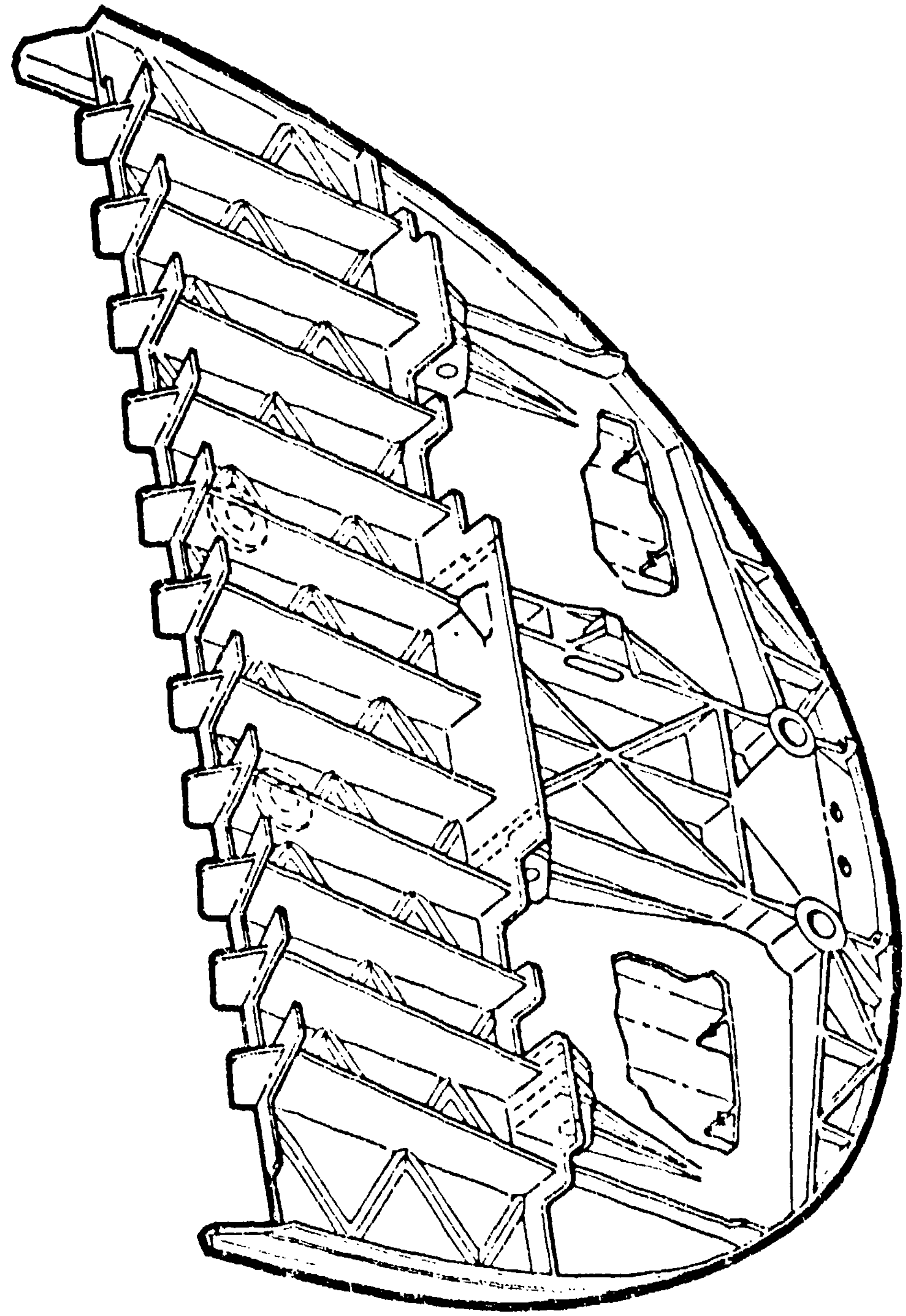


Figure 13. Concept No. 3 Truss

The goals listed above were achieved by the following design features:

- The bulkhead web is designed to minimum castable thickness and the vertical beams have flanged outer edges and zero draft.
- The interface with mating structure was designed into the cast bulkhead to match existing structure without requiring structural revision for load path continuity.
- All parts of the Baseline Component were included in the cast concept except one small clip-angle of approximately 0.2 pound.
- Reduction of parts to one cast bulkhead with machining required only to match close tolerance mating fittings.

In this concept, the weight goal was maintained without striving for the utmost in casting simplicity for maximum cost reduction.

Hybrid Concept (Cast Concept #2)

The hybrid concept was designed to meet the following goals:

- Basic YC-14 dimensional and strength requirements
- Utilization of aluminum sheet as bulkhead web in minimum gage areas
- Minimum cost through casting simplification
- Matching of cast structure to existing structural load paths
- Minimum weight consistent with above goals

The goals listed above were achieved by the following design features:

- Areas between beams and high load fittings were filled with a sheet aluminum web sized by shear load only.

- Coring requirements were held to a minimum by designing a channel-shaped chord and channel beams, both with angled surface to provide natural draft.

- The interface with mating structure was designed to match existing structure and existing load paths. An additional assembly, the WL 150 Slanted Beam, was included as part of the cast bulkhead to provide a direct interface with the slanted upper portion of the bulkhead.

- Weight was reduced by part overlap, replacement of the WL 150 slanted beam with a more efficient cast-in beam, and by using the slanted side of constant-thickness channels to provide natural draft.

In this concept, the primary goals were hybrid structure usage and simplicity of casting.

Truss Concept (Cast Concept #3)

The truss concept was designed to meet the following goals:

- o Basic YC-14 dimensional and strength requirements
- o Primary load transfer through truss members instead of shear webs
- o Minimum cost through casting simplification
- o Minimum effect on existing mating structure
- o Matching of cast structure to existing structural load paths
- o Minimum weight consistent with above goals

The goals listed above were achieved by the following features:

- o In the lower segment of the bulkhead, the jammed door load was reacted through truss members and a web for carrying landing gear fitting loads to reaction at side panels. The upper segment utilized a diamond-shaped trusswork in an effort to reduce the pressure web gage.

- o All beams and members except outer chord were designed with draft and no flanges to keep coring requirements to a minimum. The aft horizontal member at WL 130 was shortened to simplify casting.

- o The interface to existing structure was designed into the casting with the exception of the WL 130 tie to the horizontal pressure deck. Built-up structure would have to be added here to replace the shortened horizontal member noted above to complete load path requirements.

- Weight was reduced by part overlap and by retaining the angled tee outer chord concept.

In this concept, the primary goal was truss structure usage and simplicity of casting.

Evaluation Data

Cost, weight, advantages, and disadvantages were compiled for each of the three concepts (Figures 14, 15, and 16).

The weight shown was derived as follows:

- Weight of casting concept
- PLUS -- weight of baseline components not included in cast structure

  -- weight of additional built-up structure, if required
- MINUS -- weight of any additional structure utilized in casting which was not originally in baseline concept

The projected cost to a 300-airplane production run was estimated for each concept, in a manner similar to the baseline component cost estimation noted earlier under "Baseline Component Data." The percent savings from baseline cost are noted for each concept.

The pertinent advantages and disadvantages were compiled from Manufacturing, Quality Control, Structures Staff, and Structures Design inputs.

	Weight (lbs)	Cost 1 of 300 shipsets	Advantages	Disadvantages
Concept no. 1 cast - L/O-004 (Similar to as-built)	172.9	$7948 (27% savings)	• Under target wt: can absorb reduced allowable for fatigue, etc., if required • No revision to adjacent struct Includes all parts of baseline component	• Difficult areas to cast • High flanges at W.L. 130 • Beam flanges require coring • Outer chord requires coring • Core required across top at W.L. 150 • Large areas of minimum gage web
Baseline	184.6	$10,900		

Figure 14. Evaluation Chart Concept No. 1

	Weight (lbs)	Cost 1 of 300 shipsets	Advantages	Disadvantages
Concpet no. 2 Cast - L/O-002 (Hybrid)	209.4	$6,393 (41% savings)	• Casting simpliciation • Outer chord is open angle (No core required) • No beam flanges (Reduced coring) • Concept includes slanted beam at W.L.150	• Difficult areas to cast • High flages at W.L. 130 • Core required across top W.L. 150 • More fastener holes - possible crack growth problem • More difficult to inspect (NDT) • Heavyweight • Does not include radome attach parts, requires revised (heavier) seal retainer (to be used as edge stiff)
Baseline	184.6	$10,900		

Figure 15. Evaluation Chart Concept No. 2

	Weight (lbs)	Cost 1 of 300 shipsets	Advantages	Disadvantages
Concept no. 3 Cast - L/O-003 (Truss)	210.8	$7,154 (34% savings)	• Casting simplification • No beam flanges (reduced coring) • Web trusses (diamond shape) aids web flow during casting • Lowered flange height at W.L. 130	• Difficult areas to cast • Outer chord requires coring • Heavyweight • Requires new built-up intercostals at W.L. 130 • Does not include attach angle for slanted bulkhead
Baseline	184.6	$10,900		

Figure 16. Evaluation Chart Concept No. 3

PRELIMINARY DESIGN STRUCTURAL ANALYSIS

Static Strength Analysis

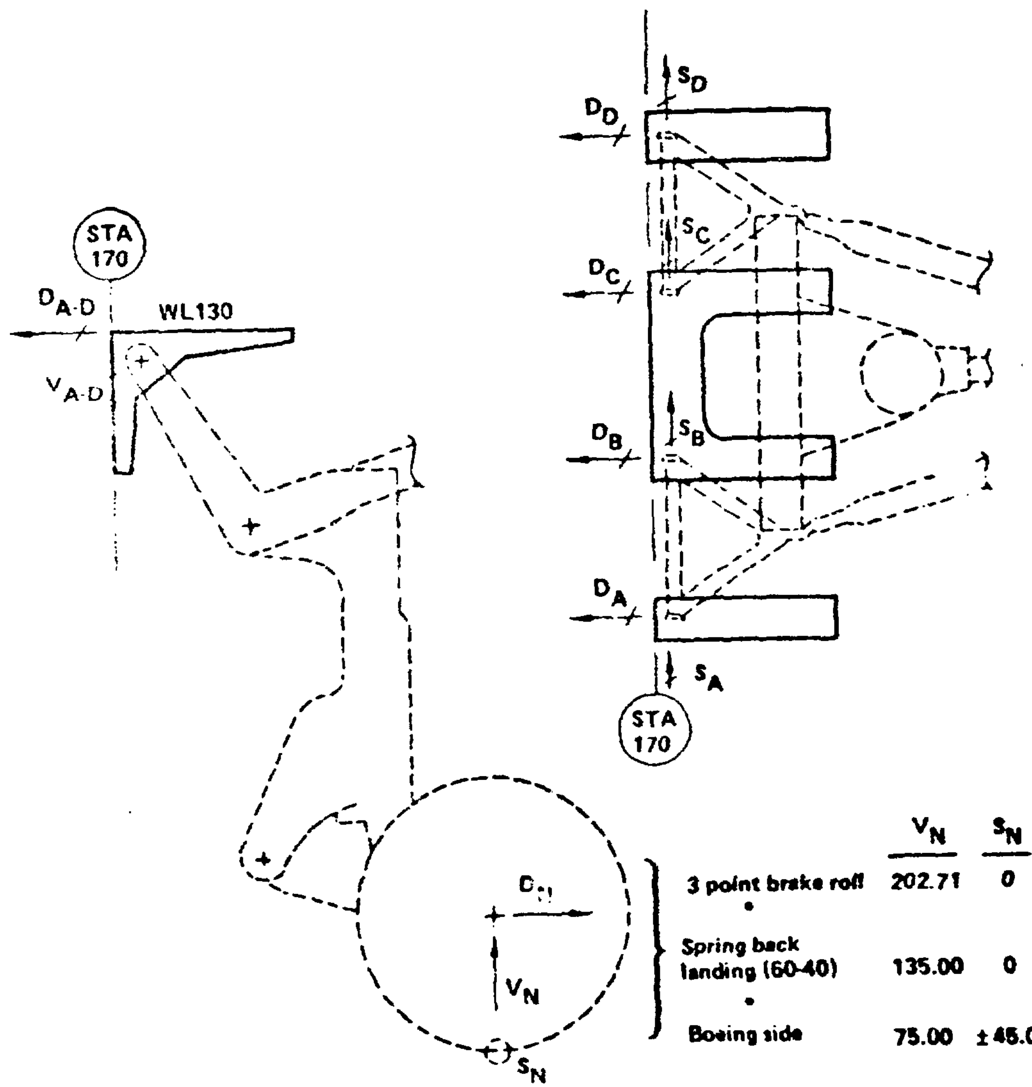
Preliminary strength analysis was performed on the three candidate bulkhead concept configurations. Structural sizing on all elements was accomplished to support weight and cost comparisons. The design loads used were those for the YC-14 existing bulkhead design, and were obtained from YC-14 Airplane Strength Analysis documentation. Pages through present detailed strength analysis for the following major elements of the recommended configuration bulkhead:

- o Critical lug (landing gear support)
- o Bulkhead webs
- o Critical vertical stiffener
- o Actuator hinge backup structure

Figures 17 through 23 show the design bulkhead loads and reactions.

Damage Tolerance Analysis

The four nose gear attachment details (Figure 24) are common to the three bulkhead concepts. Since the load attachment points are a critical item for damage tolerance consideration and since the unit load solution for these points is already available, this detail is selected for this study. Other details must also be considered, but the detail stress analysis of the bulkhead to be performed in Phase II is required before a meaningful analysis can be performed. For the purpose of this study, the cast bulkhead is classified as slow crack growth structure and in-service noninspectable.



	V_N	S_N	D_N
3 point brake roll •	202.71	0	40.54
Spring back landing (60-40) •	135.00	0	-55.88
Boeing side	75.00	±45.00	0

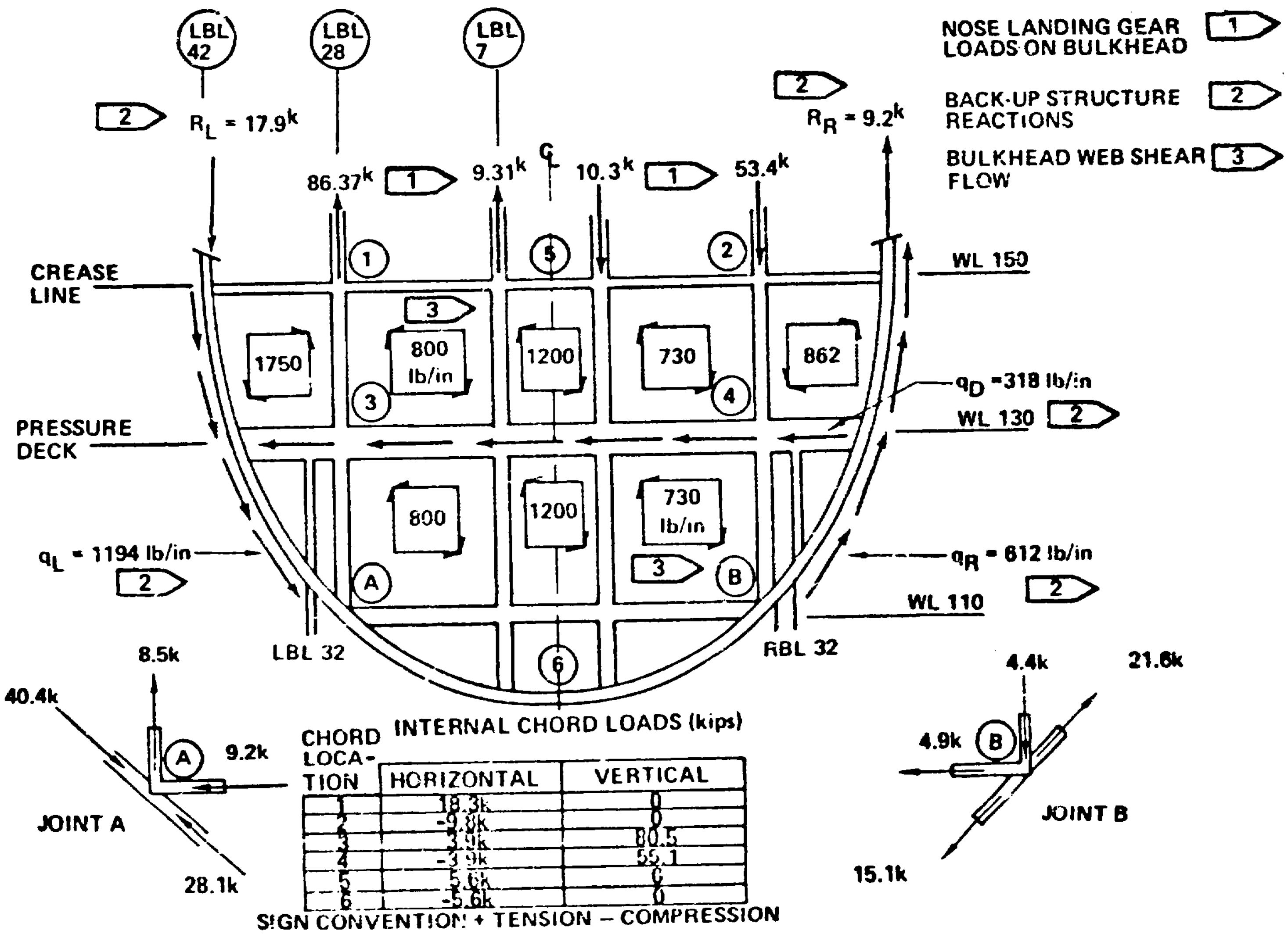
STA 170 Bulkhead and W.L. [illegible] Deck Reactions			
Condition	3 pt brk roll (60-40) •	S.B. ldg (60-40)•	Boeing S.L. ldg (50-50)• 1
V_A	-11.22	41.72	86.37
S_A	-5.61	20.85	43.19
D_A	7.60	-28.26	-58.51
V_B	36.91	31.53	9.31
S_B	-18.46	-15.76	-4.68
D_B	[illegible]	-21.36	-8.31
V_C	31.01	22.44	-10.30
S_C	15.50	11.22	-5.15
D_C	-21.00	-15.20	8.97
V_D	-30.87	29.92	-53.40
S_D	15.33	-14.96	26.70
D_D	20.77	-20.27	36.17

1 REACTIONS SHOWN FOR SIDE LOAD APPLIED TO LEFT: SIDE LOAD IS REVERSIBLE

• (KIP)

ALL LOADS ARE ULTIMATE LOADS

Figure 17. Bulkhead Loads -- Nose Gear Load Reactions

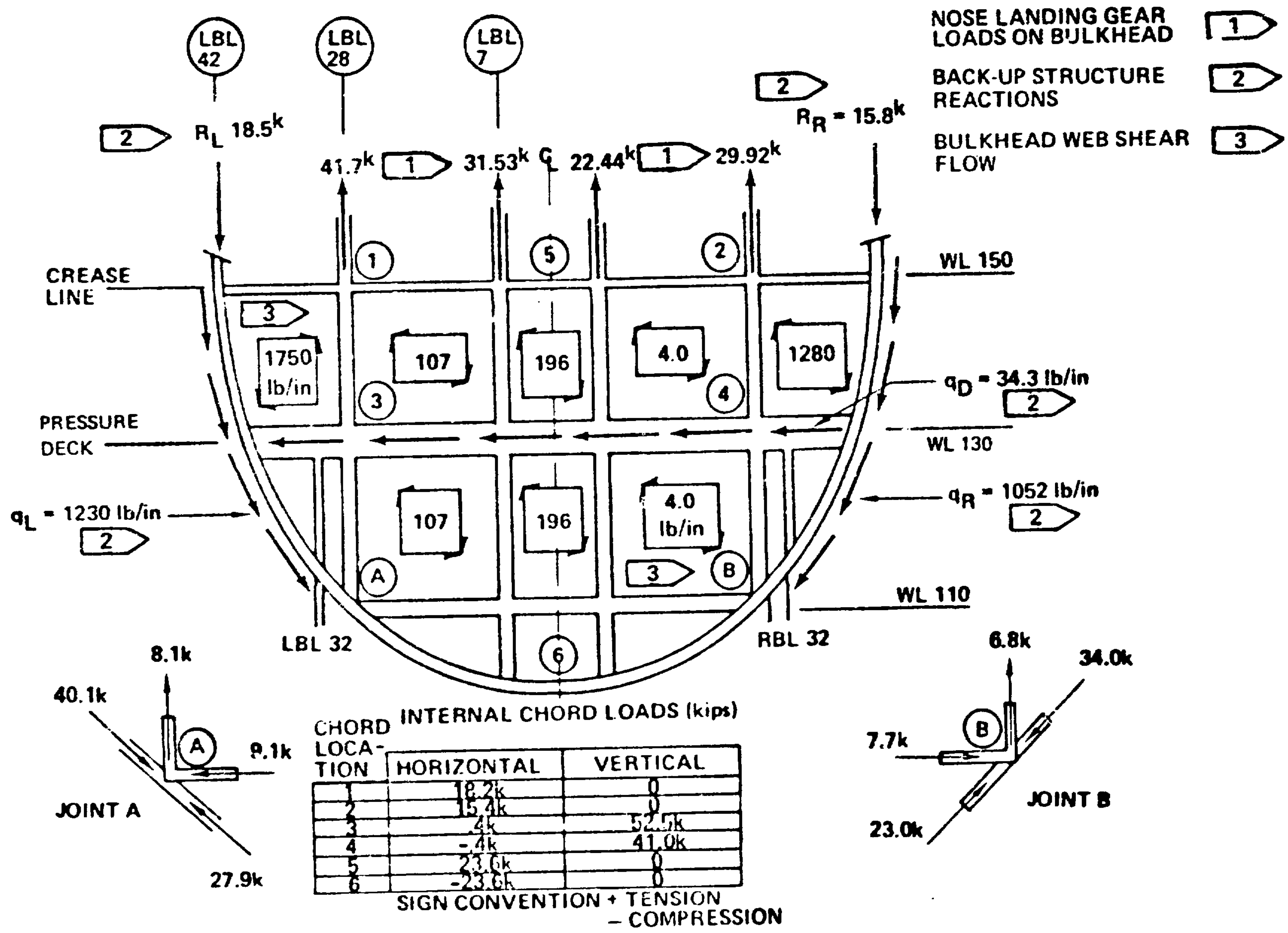


INTERNAL CHORD LOADS (kips)

CHORD LOCATION	HORIZONTAL	VERTICAL
1	18.3k	0
2	-9.8k	0
3	3.9k	80.5
4	-3.9k	55.1
5	5.6k	0
6	-5.6k	0

SIGN CONVENTION + TENSION – COMPRESSION

Figure 18. *Station 170 Bulkhead* *Landing – Side Load (50-50 Dist.) – Ultimate Loads*

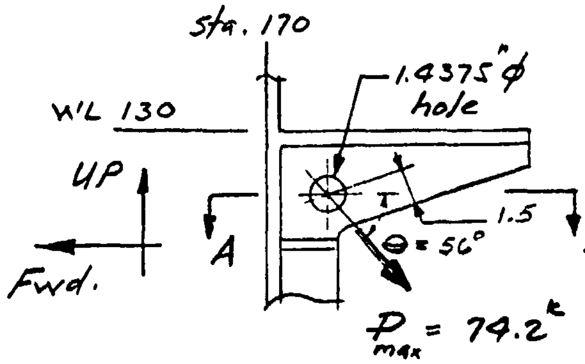


CHORD LOCATION	HORIZONTAL	VERTICAL
1	18.2k	0
2	15.4k	0
3	.4k	52.5k
4	-.4k	41.0k
5	23.6k	0
6	-23.6k	0

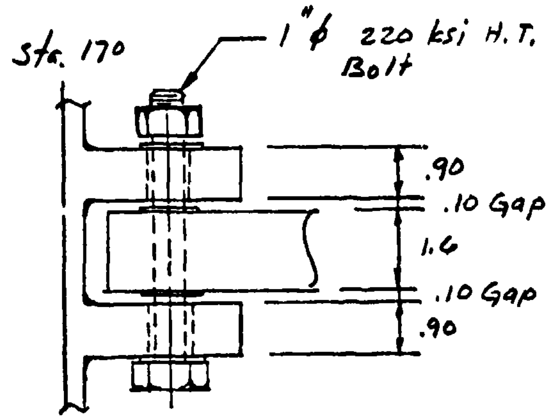
Figure 19. *Station 170 Bulkhead* *Landing – Springback (60-40 Dist.) – Ultimate Loads*

Lug Analysis @ BL 28.0 · (Critical Lug)

Material Properties - $F_{tu} = 50$ ksi
$F_{ty} = 40$ ksi
elong. = 5 %



Side View



A - A

$$P = \sqrt{V_D^2 + D_D^2} = \sqrt{53.9^2 + 36.17^2} = 64.5^k$$

Boeing Side Load Landing Fig. 1.5.1-A pg. 30

$$P_{max} = 64.5 \times 1.15 = 74.2^k \quad (15\% \text{ Fitting Factor})$$

Shear Bearing ▷1

▷1 Lug Analysis Structural Bulletin 1.712 Product Eng. June 1953

$a/D = 1.5/1.4375 = 1.04$

$D/t = 1.4375/.9 = 1.6$

$k_{br} = .81$ (Fig. 13 pg. 167 ▷1)

$P_{brg.} = k_{br} F_{tu} D t = (.81)(50)(1.4375)(1.8) = 104.8^k$

$$M.S. = \frac{104.8}{74.2} - 1 = +0.41$$

Tension ▷1 (Assume W = 3.0)

$W/D = 3/1.4375 = 2.08$

$k_t = .682$ (Fig. 12 pg. 166 ▷1)

$P_t = k_t F_{tu} (W - D)\, t = (.682)(50)(3 - 1.4375)(1.8) = 95.9^k$

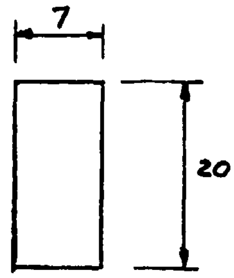
$$M.S. = \frac{95.9}{74.2} - 1 = +0.29$$

			REVISED	DATE		
ENGR.	R. Kenner	2-11-77			Lug Analysis @ BL 28.0	CAST
CHECK	J. F. [illegible]	2-16-77				
APR						
APR					BOEING	36

Bulkhead Web Analysis

Use Ref. ▷2 for Web Analysis

Material properties – $F_{tu} = 40$ ksi.
$F_{ty} = 30$ ksi.
$F_{su} = 28$ ksi.
elong. = 3 %



Typical Web Panel Size

Web $t = .10$

(Between RBL 28 and LBL 28)

$q_{max} = 1200\ \#/in$ (Fig. 1.5.1-B)

$f_s = 1.2/.1 = 12.0$ ksi

$F'_{s_{cr}} = 10.8$ ksi (Fig. 8.2.1.1-1 ▷2)

$a/h = 7/20 = .35$

$C_a = 1.095$ (Fig. 8.2.1.1-1 ▷2)

$F_{s_{cr(elastic)}} = C_a F'_{s_{cr}} = 1.095 \times 10.8 = 11.83$ ksi

$C_p = 1.0$ (Fig. 8.2.1.1-2 ▷2)

$F_{s_{cr}} = C_p F_{s_{cr(elastic)}} = 1 \times 11.83 = 11.83$ ksi

$$M.S. = \frac{11.83}{12.0} - 1 = \underline{-0.015}^{*}$$

* Acceptable for CAST preliminary design. Final loads will [illegible] lower.

▷2 Shear Resistant Web Design (See pgs. 36 & 37)

			REVISED	DATE		
ENGR	C. Kinaris	2-[illegible]			Bulkhead Web $t = .10$	CAST
CHECK	[illegible]	2-6-77				
APR						
APR					BOEING	37

Bulkhead Web Analysis (Cont'd.)

Web $t = .16$ (Between BL 45 and BL 28)

$q_{max} = 1750$ #/in (Fig. 1.5.1 - B)

$f_s = 1.75/.16 = 10.95$ ksi

$F'_{s_{cr}} = 26.6$ ksi (Fig. 8.2.1.1-1 ▷2)

$a/b = 7/20 = .35$

$C_a = 1.095$ (Fig. 8.2.1.1 - 1 ▷2)

$F_{s_{cr}(elastic)} = C_a F'_{s_{cr}} = 1.095 \times 26.6 = 29.1$ ksi

$C_p = .70$ (Fig. 8.2.1.1 - 2 ▷2)

$F_{s_{cr}} = C_p F_{s_{cr}(elastic)} = .70 \times 29.1 = 20.4$ ksi

Combine shear w/ compression –

Compression at 65 % of web panel height:

$P_{(axial)} = (1.75^k/in + .8^k/in) 20 \times .65 = 33.1^k$ (Fig. 1.5.1-B)

$f_c = P/A = 33.1/2.24 = 14.8$ ksi (See pg. 39 for area)

$a/b = 20/7 = 2.86$

▷3 $F_{c_{cr}} = kE(t/b)^2 = 3.62 \times 10.4 \times 10^3 (.16/7)^2 = 19.7$ ksi

$R_s = f_s/F_{s_{cr}} = 10.95/20.4 = .537$

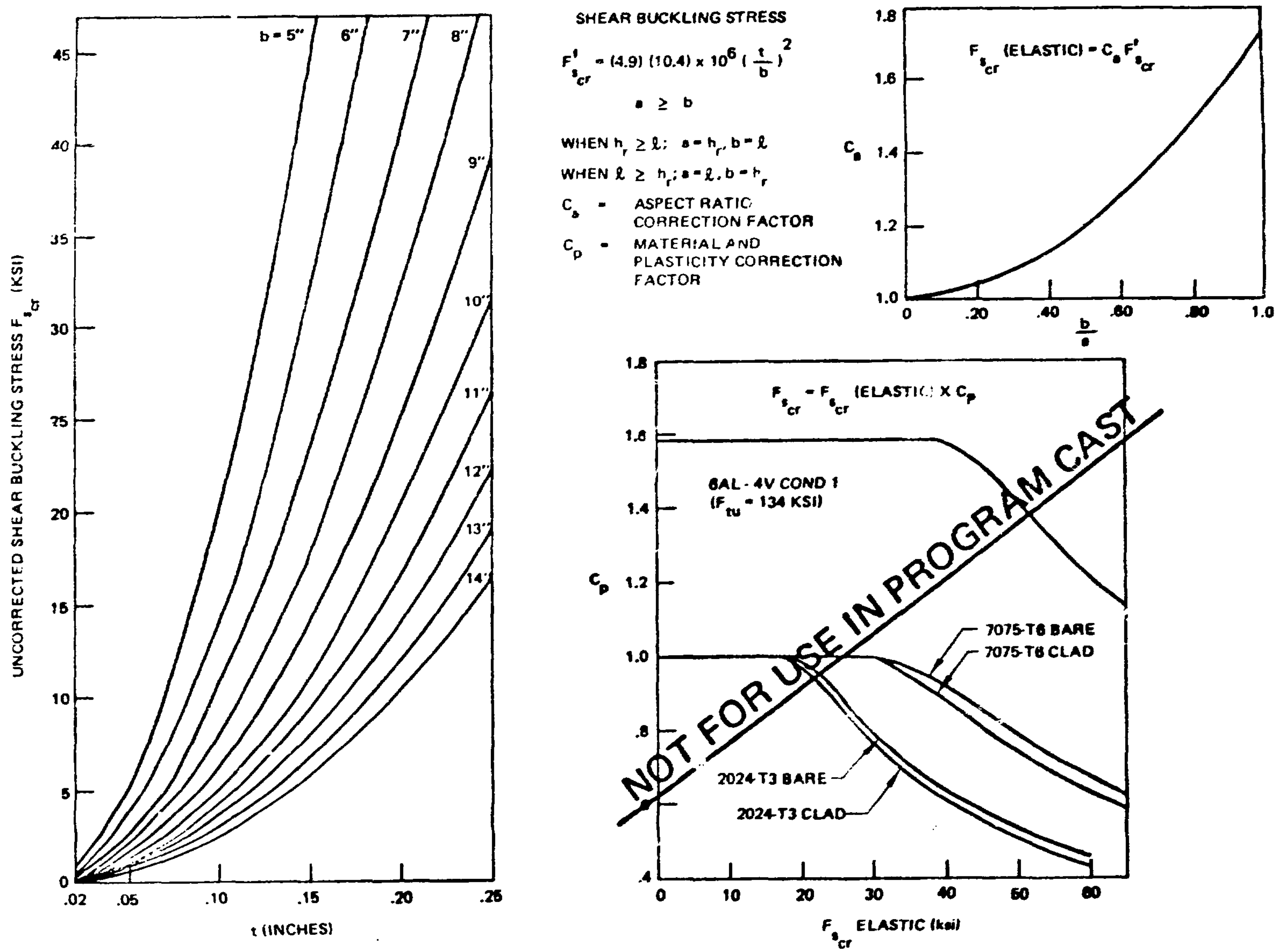
$R_c = f_c/F_{c_{cr}} = 14.8/19.7 = .751$

$$M.S. = \frac{1}{\sqrt{.537^2 + .751^2}} - 1 = \underline{+0.08}$$

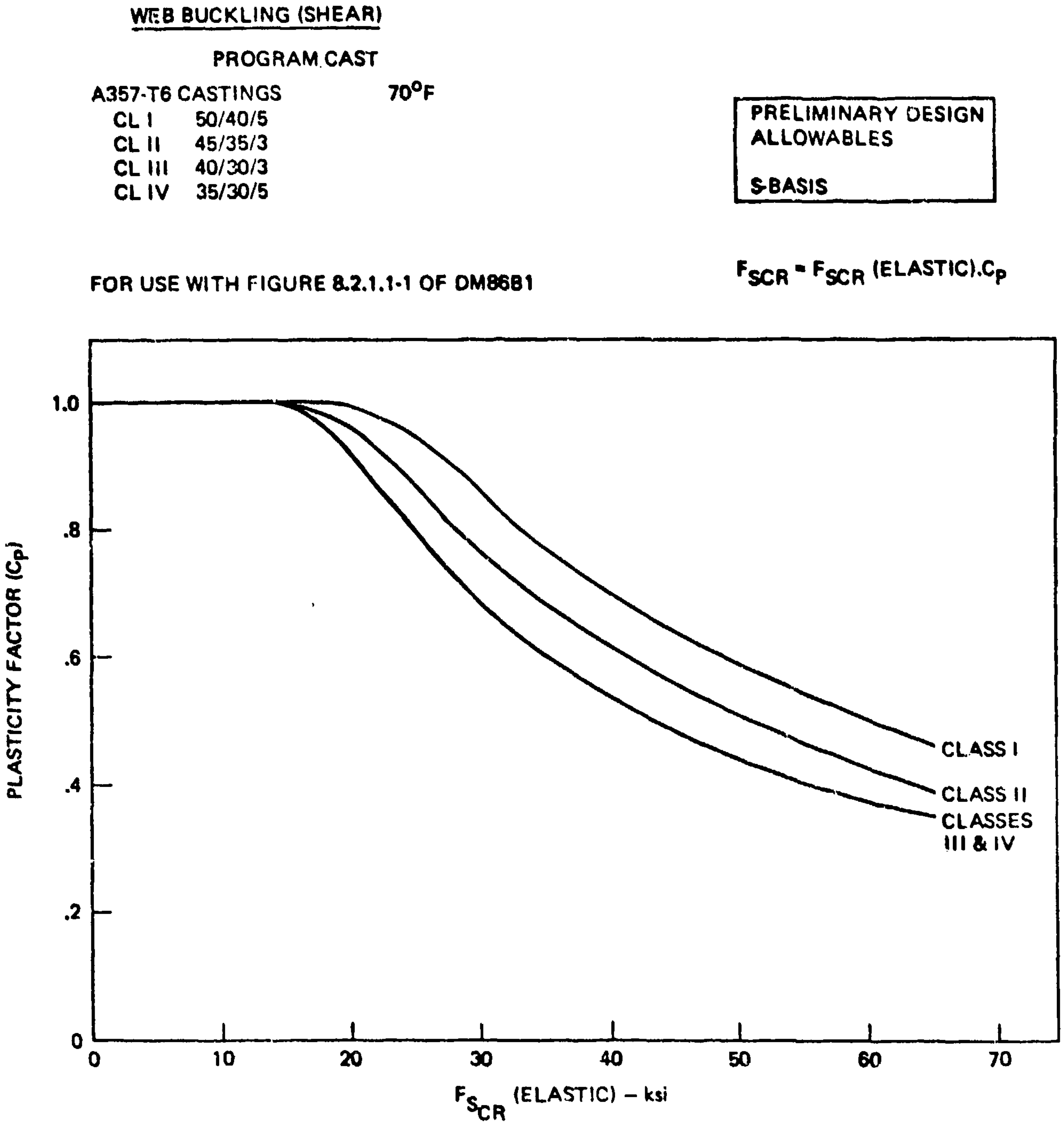
▷2 Shear Resistant Web Design (See pgs. 36 & 37)

▷3 Aircraft Structures by D.J. Perry pg. 372 Fig. 14.25

ENGR.	[illegible]	2-11-77	REVISED	DATE	Bulkhead Web t = .16	CAST
CHECK	[illegible]	2-15-77				
APR						
APR					BOEING	38



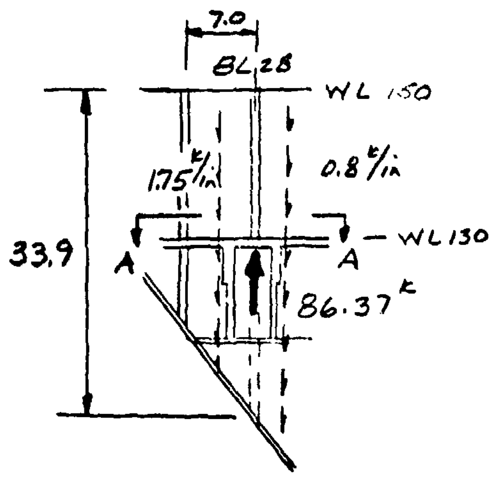
(Boeing Design Manual) Figure 20. ***Web Ultimate Shear Stress (Shear Resistant Web Design)***



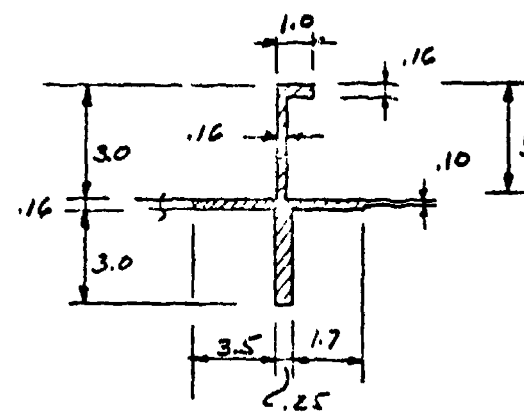
(Boeing Design Manual) Figure 21. *Shear Resistant Web Design*

Vertical Stiffener @ BL 28

Material - $F_{tu} = 40$ ksi
$F_{ty} = 30$ ksi
elong. = 3 %



Loads and Reactions in sketch are from Fig. 1.5.1-B pg. 31



Section A-A
(WL 131.5)

Section A-A analysis

Section properties - Area $= 2.24$ in²
$\bar{y} = 3.08$ in
$I_{n.a.} = 5.16$ in⁴
$e = 1.52$ in

$\boxed{4}$ Crippling : web .16 = $b/t^{*} = 7/(2.3 \times .16) = 19.0$ $F_{cc} = 21.1$ ksi
stiffener .16 = $b/t = 3/(2.3 \times .16) = 8.2$ $F_{cc} = 30$ ksi
stem .25 = $b/t = 3.08/.25 = 12.3$ $F_{cc} = 29.6$ ksi

* Vertical stiffener spacing is 7 inches on center
$\boxed{4}$ Compression Crippling Curves Fig. 1.5.1-E pg. 41

ENGR.	C. Comer	2-14-77	REVISED	DATE	Vertical Stiffener @ BL 28	CAST
CHECK	G. L. [illegible]	2-16-77				
APR						
APR					BOEING	41

<u>Vertical stiffener @ BL 28 (Cont'd.)</u>

<u>Section A-A analysis (cont'd.)</u>

Axial load (Section A-A) $= (1.75 + .8)\, 18.5^{*} = 47.2^{k}$ (pg. 38)

$P/A = 47.2/2.24 = 21.07$ ksi

$M.S. = \frac{21.1}{21.07} - 1 = \underline{0}$

(.16 web crippling)

Stem check (3 x .25)

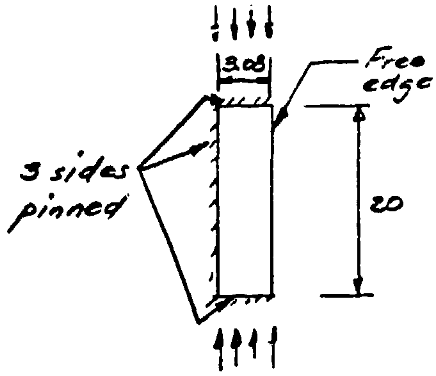
$a/b = 20/3.08 = 6.5$

$\boxed{3}\!\triangleright$ $k = .385$

$\boxed{3}\!\triangleright$ $F_{c_{cr}} = kE(t/b)^2$

$= .385 \times 10.4 \times 10^3 \,(.25/3.08)^2$

$= 26.4$ ksi



<u>Section A-A Stem</u>

$M.S. = \frac{26.4}{21.07} - 1 = \underline{+\,0.25}$

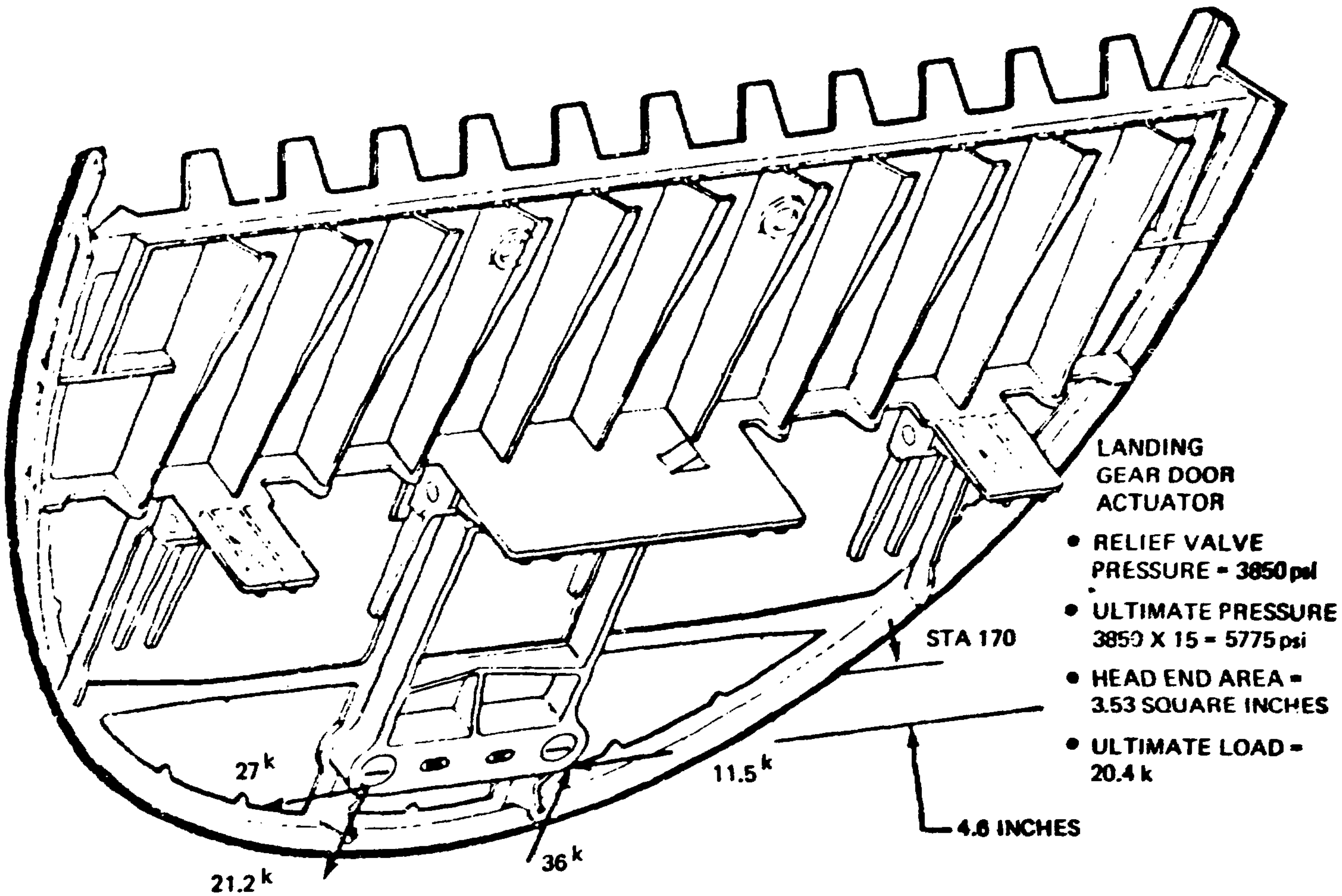
(.25 stem buckling)

$*$ Stiffener height to Section A-A is 18.5 (WL 150 to WL 131.5)

$\boxed{3}\!\triangleright$ Aircraft Structures by D. J. Perry pg. 372 Fig. 14.25

			REVISED	DATE		
ENGR.	C. Romero	2-14-77			Vertical Stiffener @ BL 28	CAST
CHECK	G. L. Golding	2-16-77				
APR						
APR					BOEING	42

D1 8007 2070 ORIG. 6/73 J18-047



MAXIMUM LANDING GEAR DOOR ACTUATOR REACTIONS (kips)—
(ULTIMATE CONDITION) DOORS IN JAMMED CONDITION (DOORS CLOSED)

Figure 22. *Station 170 Bulkhead*

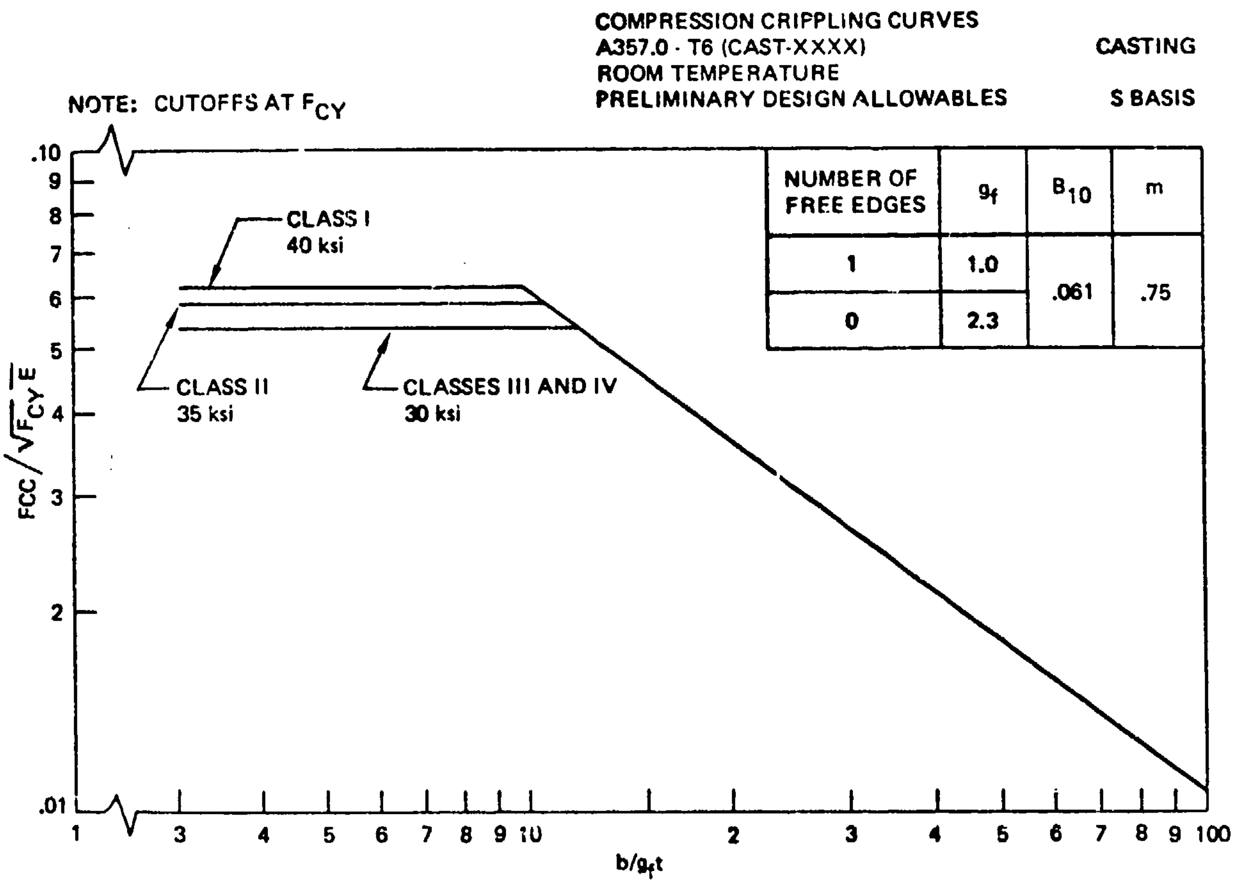
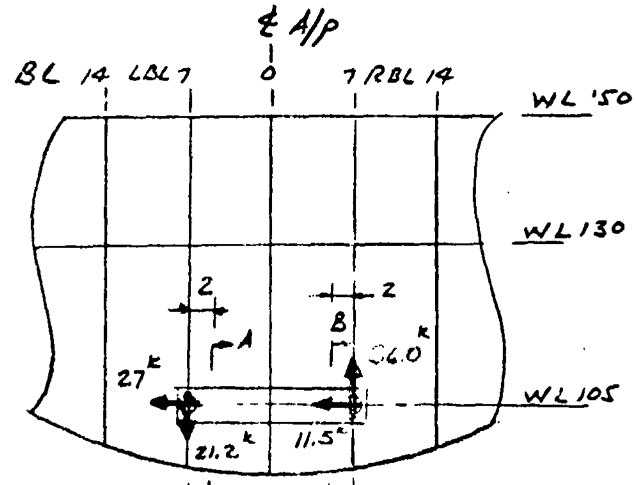


Figure 23. *Compression Crippling Curves*

Analysis of Back-up Structure for Landing Gear Door Actuator Hinges

See Fig. 1.5.1-D (for Loads)

Analysis will be performed on two sections, A-A and B-B of Torque Box. (See sketch @ right)

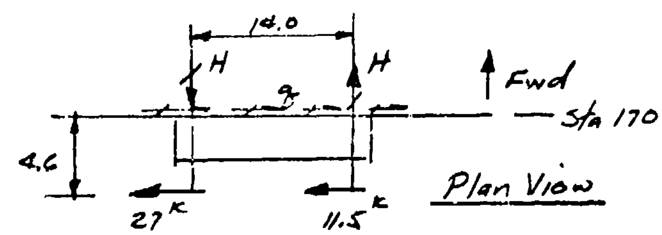


Rear View

$$H = \frac{(27 + 11.5)\,4.6}{14} = 12.65^k$$

$$M_{A\text{-}A} = 27 \times 4.6 - 12.65 \times 2 = 98.9^{\prime\prime k}$$

$$M_{B\text{-}B} = 11.5 \times 4.6 - 12.65 \times 2 = 27.6^{\prime\prime k}$$



Plan View

$$q = \frac{27 + 11.5}{14} = 2.75\ ^k/_{in}$$

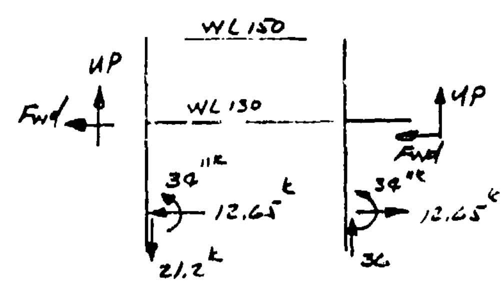
$$P_{A\text{-}A} = 27 - 2.75 \times 2 = 21.5^k \text{ (ten.)}$$

(axial load)

$$P_{B\text{-}B} = 11.5 - 2.75 \times 2 = 6.0^k \text{ (comp)}$$

$$\text{Torque}_{A\text{-}A} = 21.2 \times 4.6 = 97.52^{\prime\prime k}$$

$$\text{Torque}_{B\text{-}B} = 36 \times 4.6 = 165.6^{\prime\prime k}$$



LBL 7.0 RBL 7.0

Loads on Stiffeners

$$\text{Net External Torque/stiff} = \frac{165.6 - 97.52}{2} = 34^{\prime\prime k}$$

			REVISED	DATE		
ENGR.	C. [illegible]	2-14-77			Actuator Door Hinge Back-Up Structure	CAST
CHECK	[illegible]	2-16-77				
APR						
APR					BOEING	

D1 5007 2070 ORIG. 6/73 J1S-047

Analysis of Back-up Structure for Landing Gear Door Actuator Hinges (Cont'd.)

Section A-A & B-B Section Properties

$A = 4.96 \ \square''$

$\bar{y} = 1.44$ in

$I = 7.08 \ in^4$

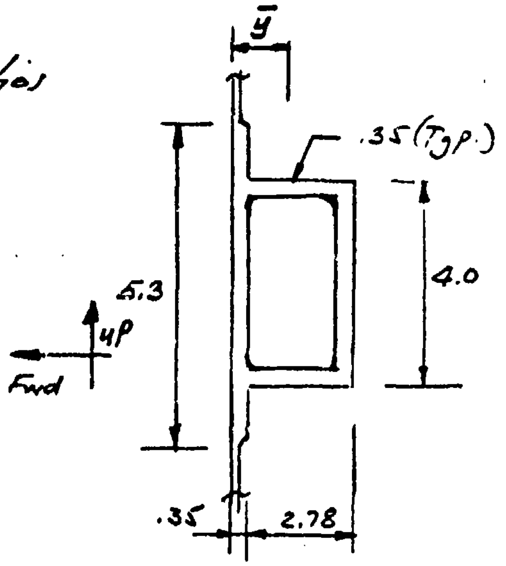
Material:

$F_{tu} = 40$ ksi.

$F_{ty} = 30$ ksi.

$F_{su} = 28$ ksi.

Elong. = 3 %



A-A & B-B

Net torque A-A & B-B -

$T_{net} = 97.52 + 34 = 131.52''^{k}$

Section A-A

$M = 98.9''^{k}$

$P = 21.5^{k}$

$T_{net} = 131.52''^{k}$

$P/A = 21.5/4.96 = +4.33$ ksi

$\frac{Mc}{I} = 98.9 \times 1.69/7.08 = +\underline{23.61}$ ksi

$+27.94 \text{ ksi} < 40 \text{ ksi} (F_{tu})$

⑤ $f_s = \frac{T}{2t(a-t)(b-t)} = \frac{131.52}{2 \times .35(4-.35)(3.13-.35)} = 18.5 \text{ ksi} < 28 \text{ ksi} (F_{su})$

Combine bending, axial, & shear -

$R_s = f_s/F_{su} = 18.5/28 = .66$

$R_b = f_b/F_{tu} = 27.94/40 = .698$

$M.S. = \frac{1}{\sqrt{.66^2 + .698^2}} - 1 = \underline{+.04}$

Section B-B - Loads are less thus ok

⑤ Formulas for stress and strain by R.J. Roark, 3rd Ed. pg. 176 Item 11.0

			REVISED	DATE		
ENGR.	[signature]	2-10-77			Actuator Door Hinge Back-Up Structure	CAST
CHECK	[signature]	2-16-77				
APR						
APR					BOEING	46

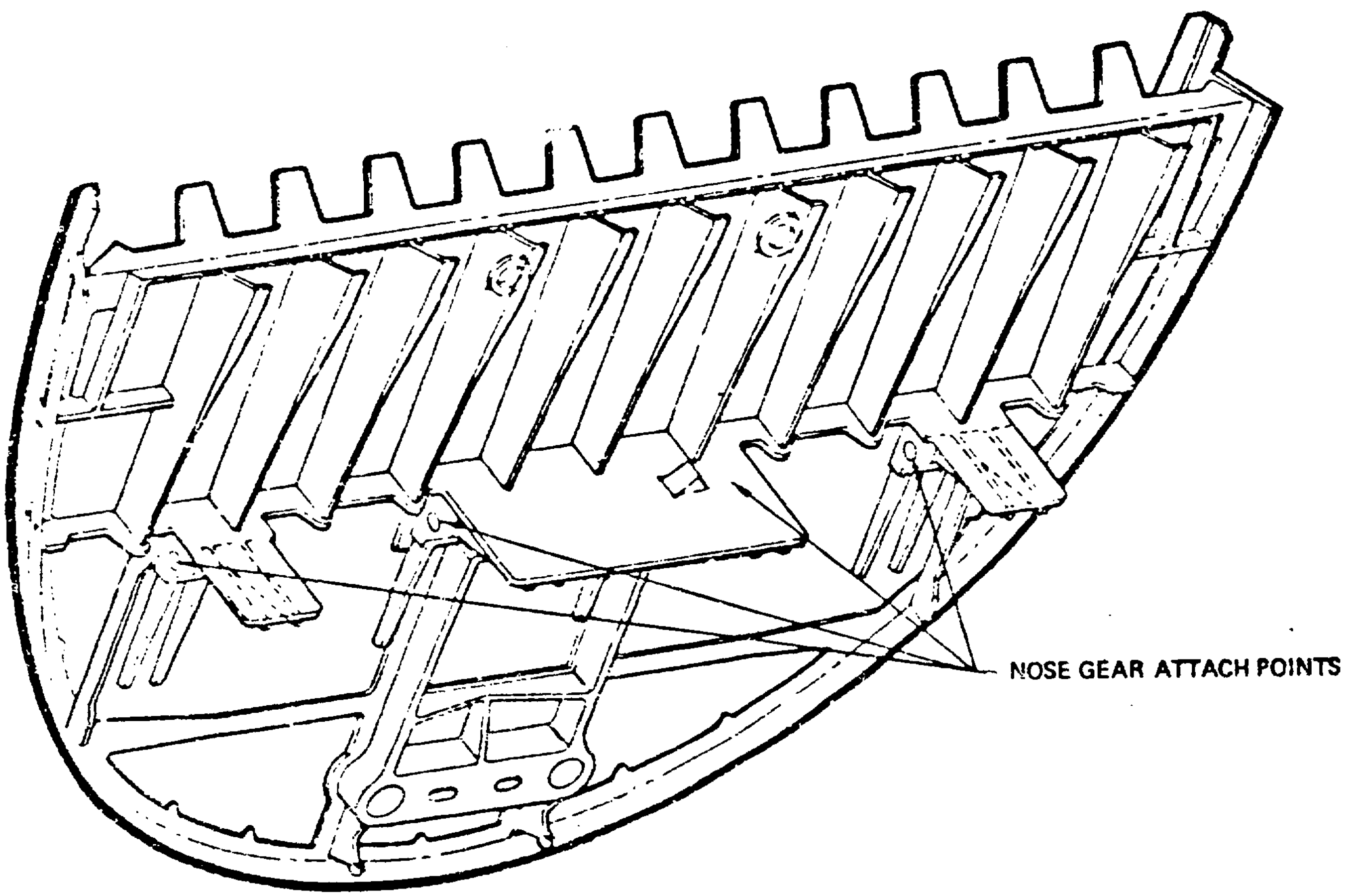


Figure 24. Nose Gear Attach Points

Initial Flaw Assumption -- In accordance with MIL-A-83444, the assumed initial flaw is a 0.05-inch radius corner flaw at the side of the hole (Figure 25). The most critical detail is either outer attachment point A or D (Figure 24).

Material Crack Growth Property -- Due to lack of any crack growth data for A357, a crack growth rate curve has been assumed (Figure 26). The equation is expressed as:

$$da/dN = (3 \times 10^{-9})\ (D)\ (K_{max})^{3.4}$$

where

$$D = \begin{cases} 0 & R \geq 1.0 \\ (1-R)^{2.4} & 0 \leq R < 1.0 \\ (1-R/2) & -1 < R \leq 0 \\ 1.5 & R < -1 \end{cases}$$

Based on the ratio of S-N data of 7075-T73 and A357, this equation is derived to give approximately the same crack growth rates for A357 as for 7075-T73 at a K-level of 80% of that for 7075-T73.

The integration of the crack growth rate equation is performed by computer program POWER6.

Stress Intensity Factor Solution -- The stress intensity factor, K, for radius corner flaws at holes is expressed as:

$$K = \sigma \sqrt{\pi a} \cdot \beta$$

The correction factor, β, is the result of a number of correction factors, i.e.,

$$\beta = \beta_1 \cdot \beta_2 \cdot \beta_3 \cdot \beta_4 \cdot \beta_5 \cdot \beta_6$$

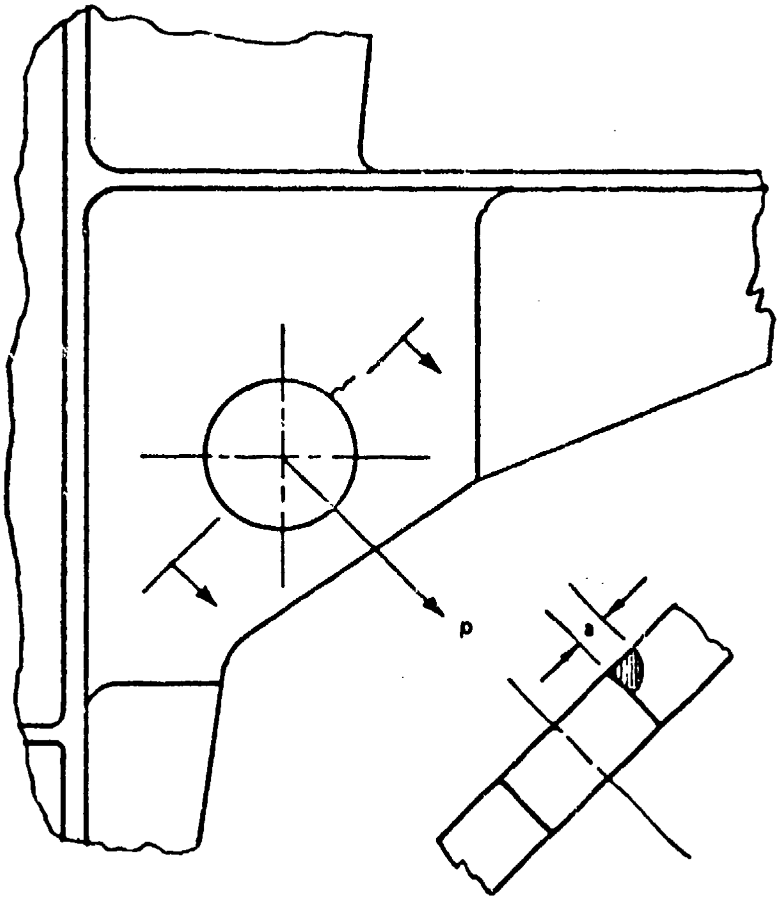


Figure 25. Initial Flaw Location

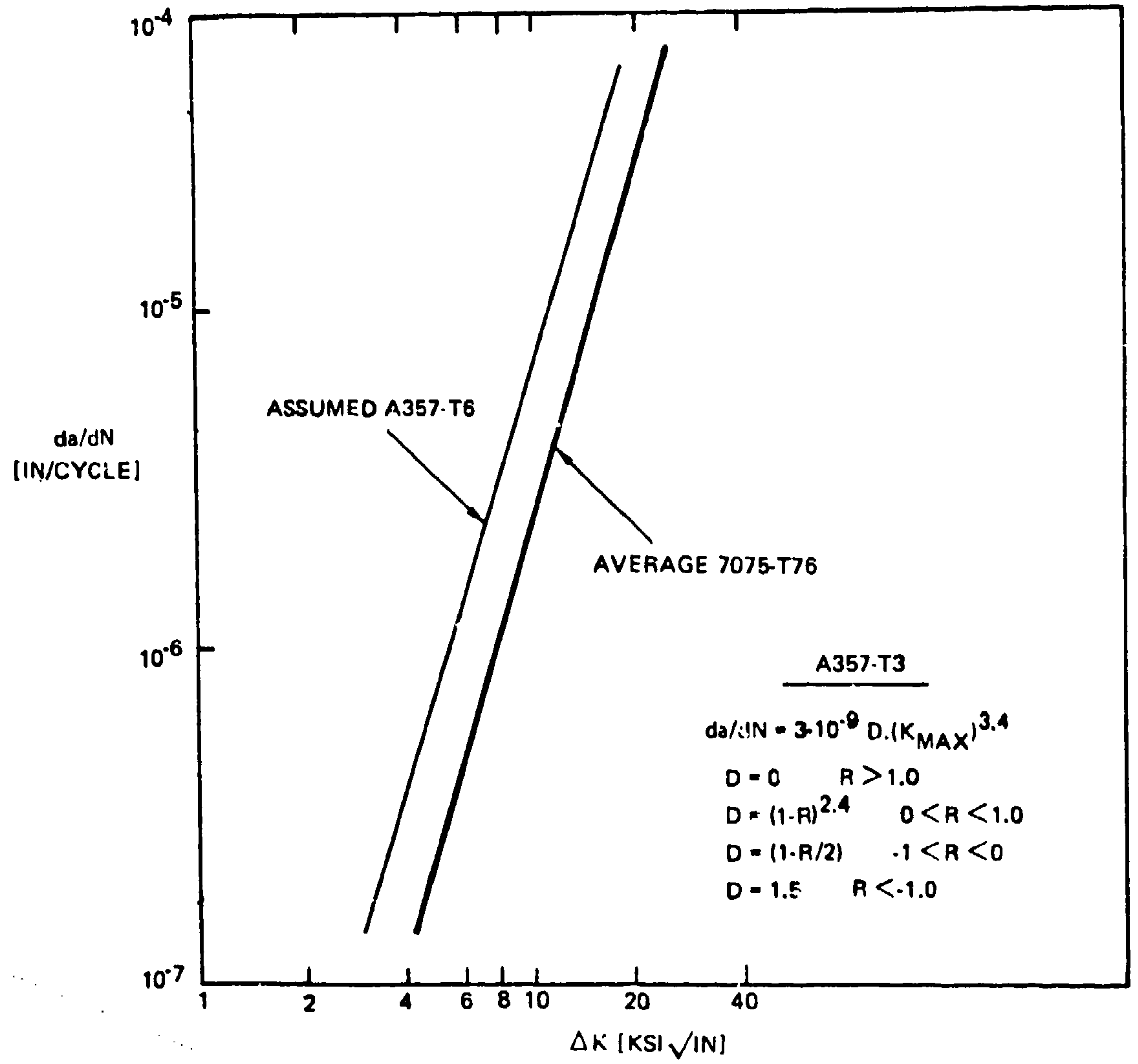


Figure 26. Assumed Crack Growth Rate – A357

The individual β_i are derived from reference 2. Over the small range of "a" to be considered for this solution and in comparison to the thickness of the material, the total correction factor, β, is assumed constant. The stress intensity factor solution is, as a first approximation:

$$K = \sigma \sqrt{\pi a} \bullet 1.45$$

The applied stress, σ, is the nominal average stress resulting from the applied load through the pin and from the assumed lug geometry.

Plane Strain Fracture Toughness -- Plane strain fracture toughness, K_{Ic}, data for A357 are reported by Alcoa. An average value of K_{Ic} = 20 ksi$\sqrt{in}$. is assumed for the analysis.

Repeated Loads -- The repeated external loads noted in the Damage Tolerance and Durability Control Plan for the CAST Program are used for the analysis. The stresses applied are representative of the design usage as given by the mission-mix reported in the control plan. Local detail stresses are derived based on unit load solutions for the gear attachment points.

Results -- The crack growth of the corner flaw due to the design usage is as shown in Figure 20. According to MIL-A-83444, the initial damage of in-service noninspectable slow crack growth structure shall not grow to critical size and cause failure of the structure due to the application of P_{LT} in two design service lifetimes. Figure 27 demonstrates that this requirement is met. The initial corner flaw grows to 0.10 inch in two service lives. The critical size is 0.17 inch for the load P_{LT}, which is determined as the design limit load due to turning.

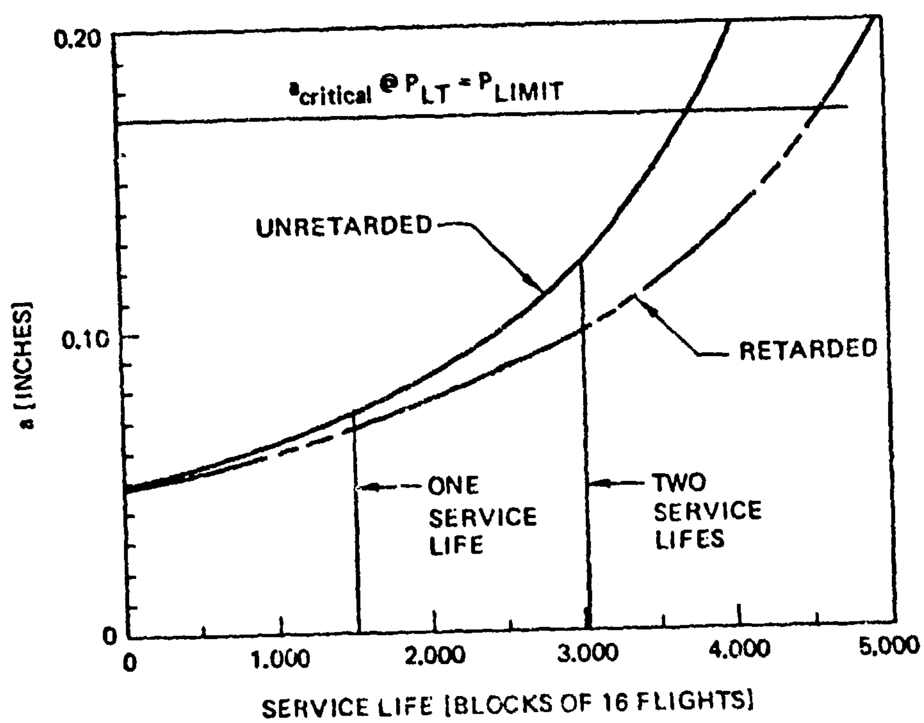


Figure 27. Flaw Growth at Hole of Gear Attachment Point

Durability Analysis

The two nose gear attachment details, A and D (Figure 24), are the most critical for durability considerations. They are common to all three bulkhead concepts. The loads acting on these details can easily be calculated from external loads using the unit load solutions. The Boeing Durability Method is used for the calculations.

Detail Design S-N Curves -- Detail design S-N curves for A357 are derived from Alcoa data (Figure 28). Design S-N curves for smooth and open hole details (Figure 29) are derived from the test data by applying appropriate factors to achieve 95% confidence and 95% reliability on a Weibull distribution.

Detail design S-N curves are expressed by two parameters: a detail fatigue rating, DFR, and slope ratio, S. The slope ratio, S, is generally kept constant at 2.0 for aluminum and titanium alloys. The slope ratio for steels is assumed as S = 1.8. The geometric severity of a particular detail considering its fatigue performance is therefore expressed by the DFR.

For a clevis or lug detail, the DFR is derived from:

$$DFR = DFR_{BASE} \cdot A$$

The DFR_{BASE} value accounts for the particular geometry of the clevis or lug. Since the DFR_{BASE} charts are presently derived for wrought aluminum alloys, the factor A accounts for the effect of the casting alloy. The factor A is derived from the ratio

$$A = \frac{DFR\ (\text{OPEN HOLE A357})}{DFR\ (\text{OPEN HOLE 2024})}$$

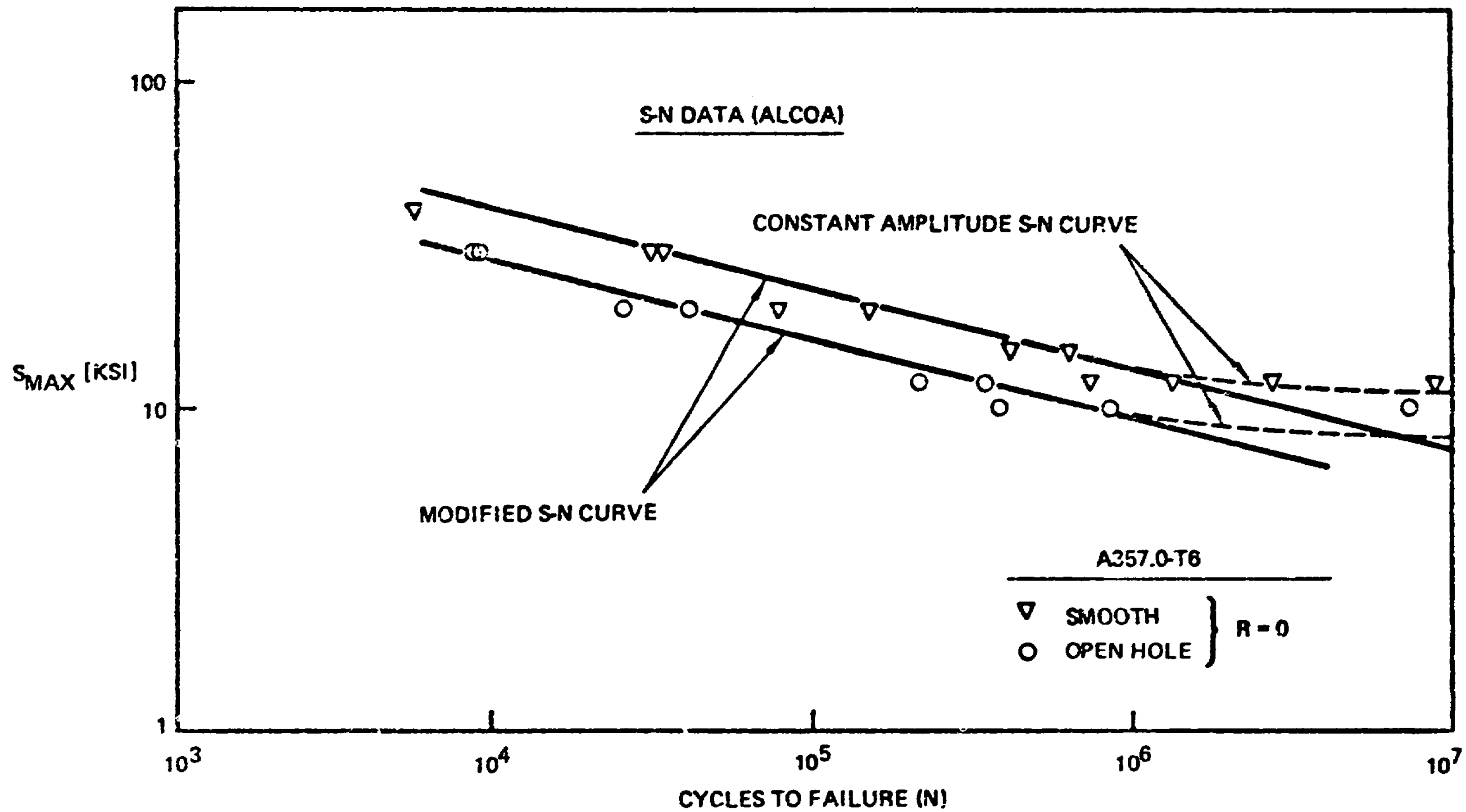


Figure 28. *A357 S-N Data*

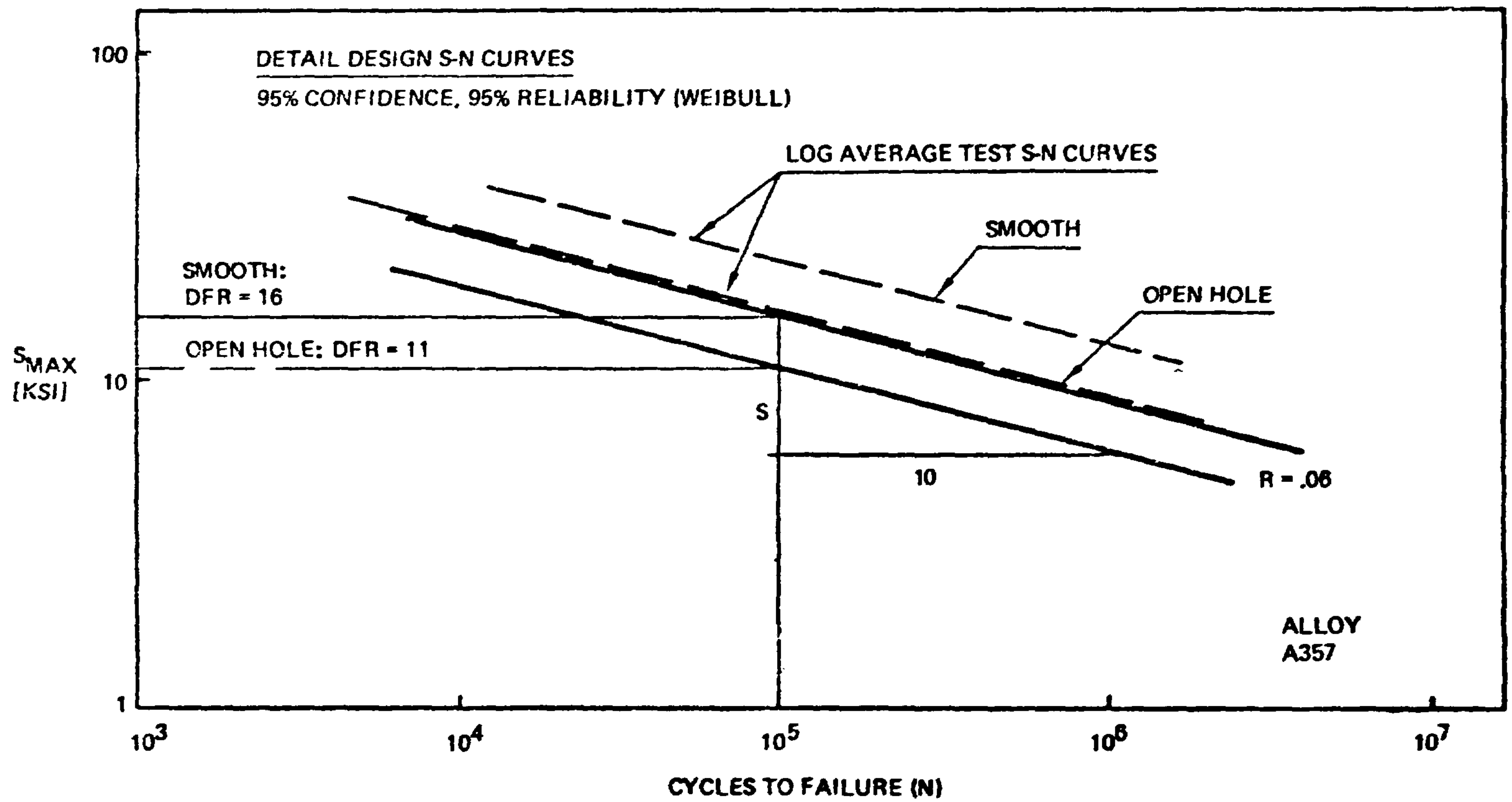


Figure 29. *Detail Design S-N Curves*

where DFR′ (open hole A357) is as shown on Figure 29 and DFR (open hole 2024) is obtained from durability design charts.

Therefore,

$$A = \frac{11}{16.5} = .67$$

The DFR for the detail in consideration is

$$DFR = (DFR_{BASE})\ (A) = (12)\ (.67) = 8$$

The value for DFR_{BASE} is obtained from the durability design charts for the particular geometry.

Economic Life -- The economic life of the cast bulkhead is predicted for the design usage as represented by the mission mix noted in the Damage Tolerance and Durability Control Plan for the CAST Program. The relative damage due to the five different flights within the mission mix consisting of 16 total flights is calculated and summarized in Table 3.

The relative damage of each flight is the sum of the damages of the individual stress excursions applied during each flight. The relative damages for the individual stress cycles are calculated from the S-N curves by

$$\text{relative damage} = \frac{100{,}000}{N_{S-N}} \quad N \text{ applied}$$

A relative damage of 1.0 for an individual cycle means that fatigue failure is predicted after 100,000 applications of that stress cycle and assuming a DFR of 16. The GAG damage ratio is calculated from

Table 3 -- Relative Damage

Flight Type	No. of Flights	Damage Each Flight	Total Damage	GAG Damage Each Flight
1	1	.0805	.0805	.0720
2	4	.0805	.3220	.0720
3	3	.1564	.4692	.0373
4	5	.0536	.2680	.0373
5	3	.2753	.8259	.0373
	16		1.9656	

average damage per flight = .1229

average GAG damage = .0482

$$\text{GAG damage ratio} = \frac{\text{relative damage GAG cycle}}{\text{relative damage total flight}}$$

and is therefore independent of DFR.

The average relative damage of the GAG cycles is established as

relative GAG damage = .0482 (ref: Table 3)

The average GAG damage ratio is:

$$\frac{.0482}{.1229} = .39$$

For the life predictions, the GAG cycle will be used in place of the variable amplitude flight stress excursions. For that purpose, an equivalent number of cycles for the GAG excursions must be established as the life goal. The design service life of the bulkhead is 25,000 hours. Using the average duration for one flight of 1.03 hours, the number of flights is 24,272. The equivalent number of GAG cycles for the life requirement is

$$N_{equ} = \frac{(N_{FLIGHTS})\ (FRF)}{\text{GAG damage ratio}}$$

$$N_{equ} = \frac{(24272)\ (1.5)}{.392} = 92{,}880 \text{ cycles}$$

An additional fatigue reliability factor, FRF, is applied in accordance with the Boeing Durability Method. This factor is mainly a function of the location of the analysis detail on the airplane.

Using the detail design curve defined by a DFR = 8 for the detail in question results in a life prediction expressed in terms of GAG cycles of 150,000 cycles. In terms of hours, the economic life is predicted as

$$\text{Life} = (25000)\left(\frac{150000}{92880}\right) = 40{,}380 \text{ hours}$$

SECTION III

CANDIDATE DESIGN SELECTION

CONTRACTOR EVALUATION AND RECOMMENDATION

A comparison chart (Figure 30) was prepared listing the weight, cost with percent differential, primary advantage, and primary disadvantage for each of the three concepts, with the baseline weight and cost also noted. None of the three concepts meets both primary criteria -- equal or less weight and a minimum of 30% cost reduction.

A composite concept (Figure 31) was established that has an estimated weight of 9.8 pounds less than baseline and an estimated cost reduction of 38% (Figures 32 and 33). This concept is based primarily on concept #1 with minimum gage webs, angled tee outer chord, and vertical beams matched to existing structure. The first revision, inclusion of the slanted beam at WL 150, is very efficient in that the beam can be simply cast-in and replaces approximately 158 separate parts, reducing both weight and cost. The second revision, deleting outstanding flanges and adding draft to the aft beams, adds weight but reduces cost through reduction of coring requirements. Further refinement in detail design is assumed with no weight credit assigned.

This composite concept was established as the Contractor recommended cast concept bulkhead to be carried into Phase III, "Detail Design," of the CAST program.

Concept no.	Weight (lb)	Cost 1 of 300 shipsets	Primary advantage(s)	Primary disadvantage(s)
1	172.9	$7,948 (-27%)	Lowest weight: under target weight	Highest cost due to casting complexity
2	209.4	$6,393 (-41%)	Least cost due to casting simplicity of outer chord and inclusion of beam at WL 150	Approximately 25 pounds over target weight
3	210.8	$7,154 (-34%)	Less cost than no. 1 due to deletion of beam flanges and lower flange height, WL 130	Approximately 26 pounds over target weight. Requires additional built-up structure (WL 130)
Baseline	184.6	$10,900	——	——

Figure 30. Concept Comparison

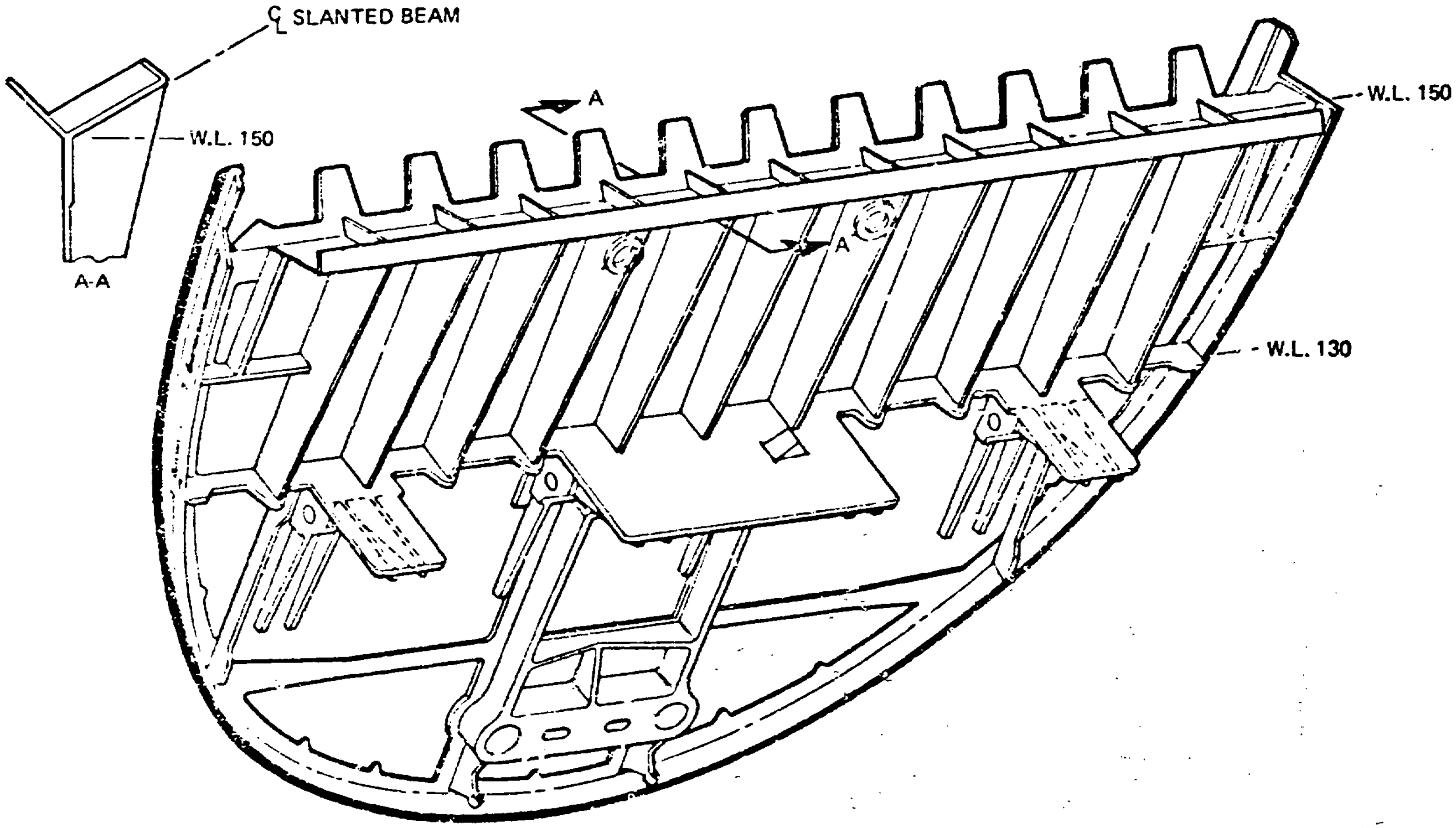


Figure 31. *Recommended Cast Concept for Detail Design : Station 170 Body Bulkhead*

Concept no. 1 (Cast-L/O-004) revised as shown:	Estimated Δweight	Estimated Δcost
• Include slanted beam at W.L. 150: Similar to concept no. 2 (Cast-L/O-002) Adds beam assy (748-141202-1 to baseline component)	–10.5 lb	$–840./unit
• Delete beam flanges - aft side only Note: Forward beam flanges to be retained along with closed angle chord - deletion of all coring requirements on aft side of bulkhead will be design goal	+12.4 lb	$–355/unit
• Tailor all beams in height and thickness to match final refined load requirements	—	—
	+1.9 lb	$–1,195/unit

Figure 32. Cost and Weight Increments to Concept No. 1

	Weight (lb)	1 of 300 cost
Concept no. 1	172.9	$7,948
Revisions	+1.9	-1,195
Recommended concept	174.8	$6,753
Baseline component	184.6	$10,900

Δ weight = − 9.8 lb (provides allowance for weight increases during detail design for fatigue, damage tolerance, and revisions for further cost reduction)

$$\Delta \text{cost} = \frac{10{,}900-6{,}753}{10{,}900}(100) = 38\% \text{ reduction}$$

439 parts + fasteners replaced by one casting

Figure 33. Recommended Casting Cost and Weight Summary

ON-SITE REVIEW

An on-site review was held on February 7 and 8, 1977 at Boeing with the customer and second source supplier representatives in attendance. A complete review of the program to date was presented, ending with the recommendation of the composite concept for detail design as noted above.

The customer review team requested further study of the recommended concept for detail design. This further study consisted of evaluating a corrugated upper web in the cast bulkhead to facilitate casting operations.

FINAL DESIGN SELECTION

A design layout of the revised CAST concept for detail design, Station 170 bulkhead, was completed. This concept has the outer chord, upper beam, and landing gear fittings similar to the concept recommended by the contractor for detail design. The upper web is corrugated with a transition to stiffened web below WL 130 (see Figure 34).

The revised concept resulted from the comments of the customer during the on-site review noted above. There was concern that the return flanges and web-to-stiffener junctions of the previously recommended concept would be a source of casting defects such as shrinkage and dimensional mismatch. The corrugations of the revised concept avoid these junctions and backdrafts, while being fairly easy to cast.

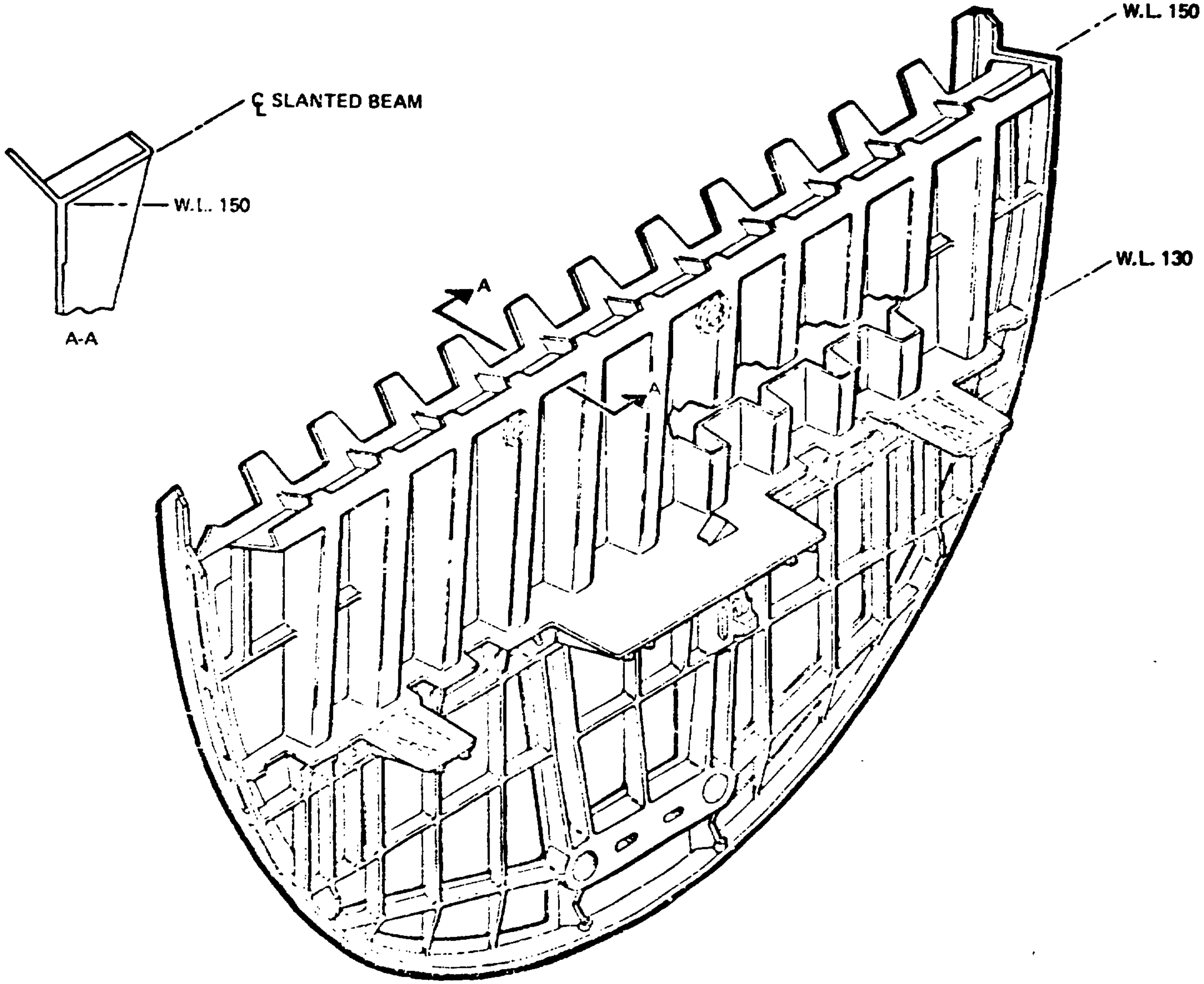


Figure 34. Revised Cast Concept for Detail Design: ***Station 170 Body Bulkhead***

Weight analysis of the new concept indicated weight equal to the recommended concept, which is approximately 10 pounds under the weight of the baseline component.

Manufacturing comments were solicited with the result that the new, corrugated web concept was favored for detail design in Phase III, on the basis of reduced risk of casting defects resulting in the possibility of further cost reductions.

The concept layout data and comments were presented to the customer at a second review meeting, where it was verbally agreed to use the new corrugated concept in Phase III Detail Design.

REFERENCES

1. Alcoa Bulletin, "Mechanical Properties, Fracture Characteristics and Fatigue Tests of Premium-Engineered Casting Alloys," Alcoa, Corona, California.

2. L. R. Hall, R. C. Shah, and W. L. Engstrom, "Fracture and Fatigue Crack Growth Behavior of Surface Flaws and Flaws Originating at Fastener Holes," AFFDL-TR-74-47, Vol. 1, May 1974.